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INSTRUMENTS

THE MAGAZINE OF MEASUREMENT AND CONTROL

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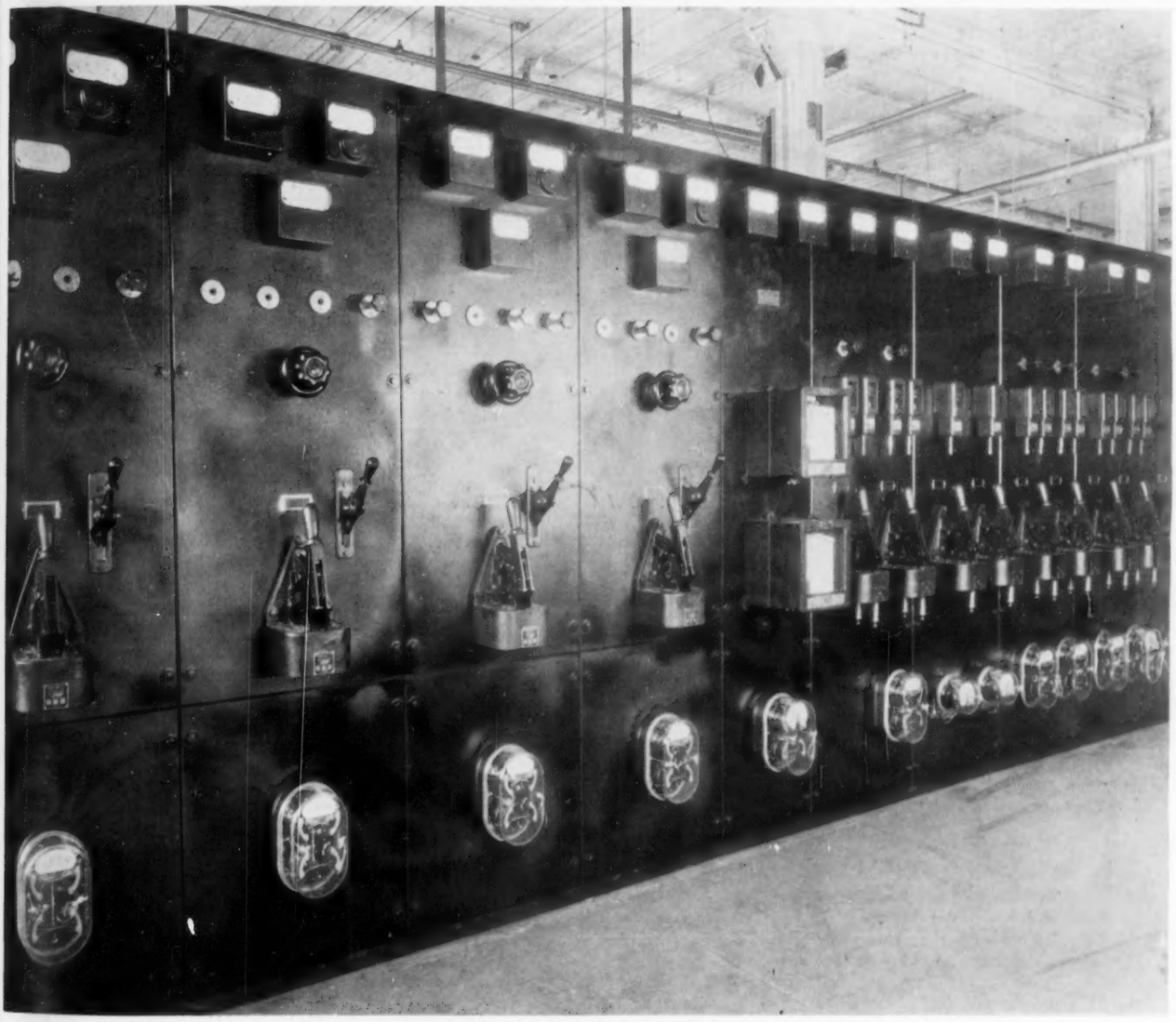

TYPICAL MODERN OPEN TYPE SWITCHBOARD (*Courtesy Roller-Smith Co.*)

INSTRUMENTS

THE MAGAZINE of MEASUREMENT and CONTROL

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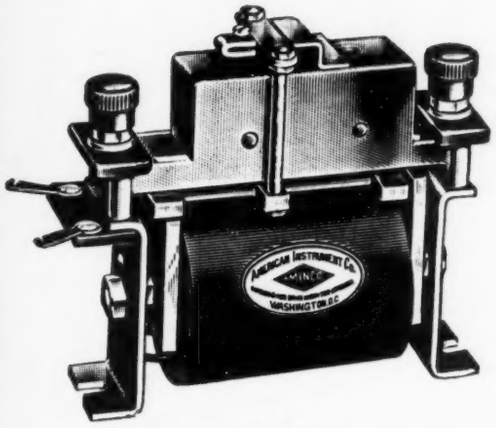
AMINCO'S RELAY...



Aminco's Relay for use with Manostats, Hygrostats, Mercury Thermoregulators and other contact-making instruments where low operating currents are desirable or necessary to control heaters, lighting loads and fractional h.p. motors. It is 3⅝" x 3½" x 1¾".

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new in

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NEW, MODERN CASE DESIGN

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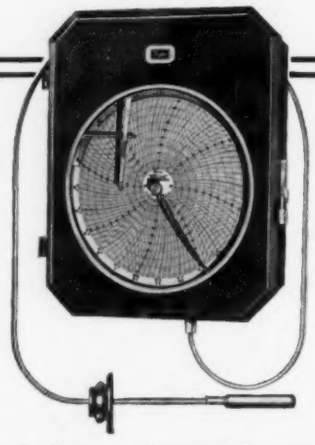
THESE new temperature and pressure recorders have now replaced all Taylor instruments previously listed for industrial use where accurate, hour-by-hour temperature or pressure records are essential.

The first feature is the new die-cast rectangular case, the creation of an eminent modern American commercial designer. The clean-cut, simple lines give a distinctive and stimulating new beauty to this type of instrument. Modern art appears on the instrument panel board.



New in beauty . . . improved in accuracy and durability—the new Taylor Recording Thermometer. The same case and outward appearance obtain for the new Taylor Recording Pressure Gauge.

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The inner mechanism is improved and refined so that it sets even higher standards of durability and accuracy in recorder performance. Here are outstanding features:

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2. Longer and more flexible pen-arm made of stainless steel (18-8). This gives better chart records due to less pen friction.

3. Micrometer adjustment of precision accuracy is provided for setting the pen-arm. Minor adjustments are made easier.

These new temperature and pressure recorders are available as mercury-, vapor- or gas-actuated instruments.

ING . . .

instruments from Taylor

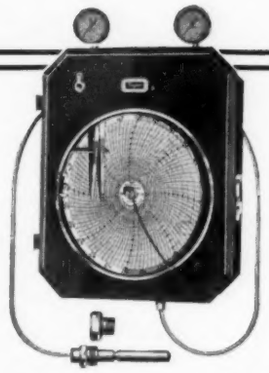
REGULATORS WITH THE WITH IMPROVED MECHANISM

New Taylor Recording Regulators for Temperature and Pressure

THE new Taylor Recording Regulators have the same die-cast cases with the simple, dignified lines and the same features that make the new Taylor Recorders distinctive in style and beauty. The following features are especially important:

1. A new method for balancing instrument performance to sensitivity of apparatus. The result is optimum control for a given set of operating conditions.

2. Reversal of the regulator action is quickly and easily accomplished without any extra parts.



Beauty, style, protection for inner mechanism —you get all three in this new Taylor Recording Regulator. Like the new Taylor Recording Thermometer, this instrument is a general purpose regulator for use in any industry.

3. Provision for micrometer adjustment in setting control point. When manually changing the control point, small increments of set pointer movement can be made easily.

4. Incorporation of air pressure compensator. This contributes to accurate control when air supply pressure varies.

All three of the features mentioned previously under the new Recorders are also to be found in the new Taylor Recording Regulators.

For any other information regarding these new Taylor Instruments and their use in your particular plant, get in touch with a Taylor Representative. Or write Taylor Instrument Companies, Rochester, N. Y.

† Taylor

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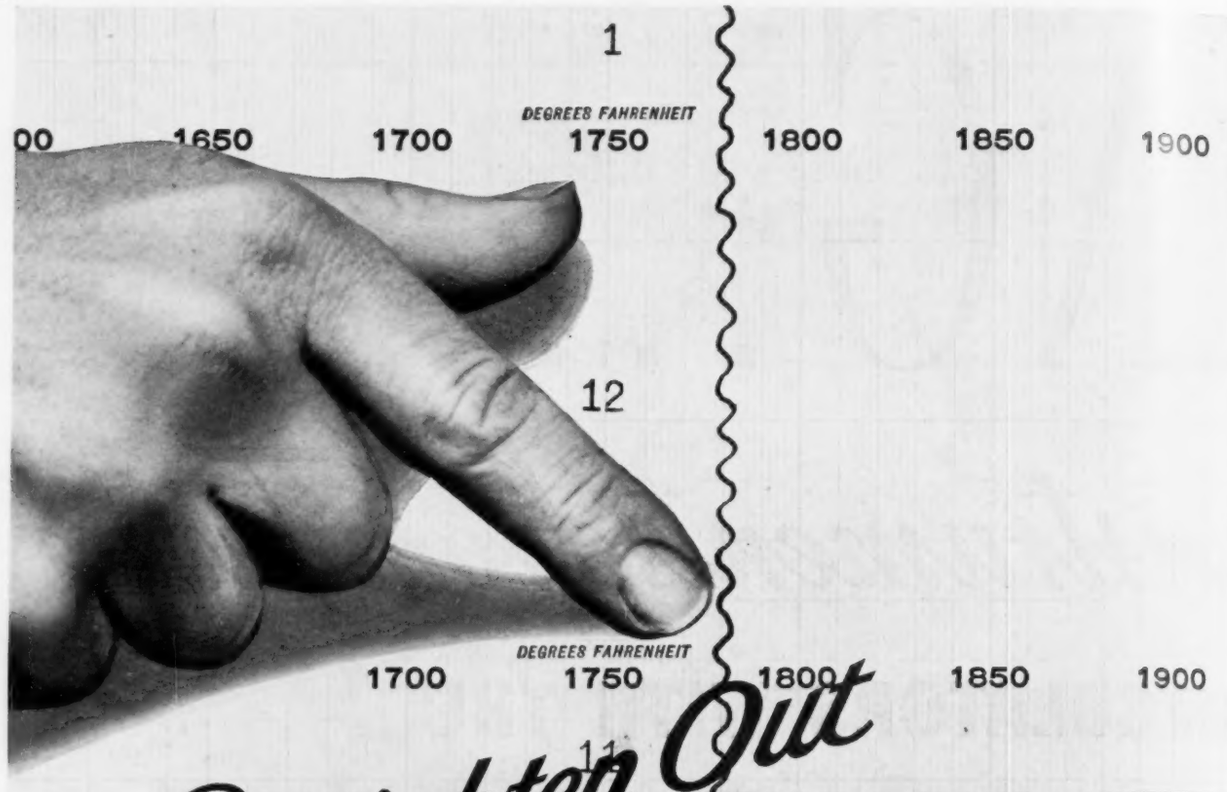
TEMPERATURE *and* PRESSURE INSTRUMENTS

† The name Taylor now identifies our complete line of products including Tycos instruments.



Straighten Out These Costly Temperature Changes

CONTROL LIKE THIS *Cuts Costs*

"Zig-zagging temperatures" mean waste—steady, "straight-line" TRENDALIZER control means better products, fewer rejects and fuel savings.

"WE DO OUR PART"

The BROWN

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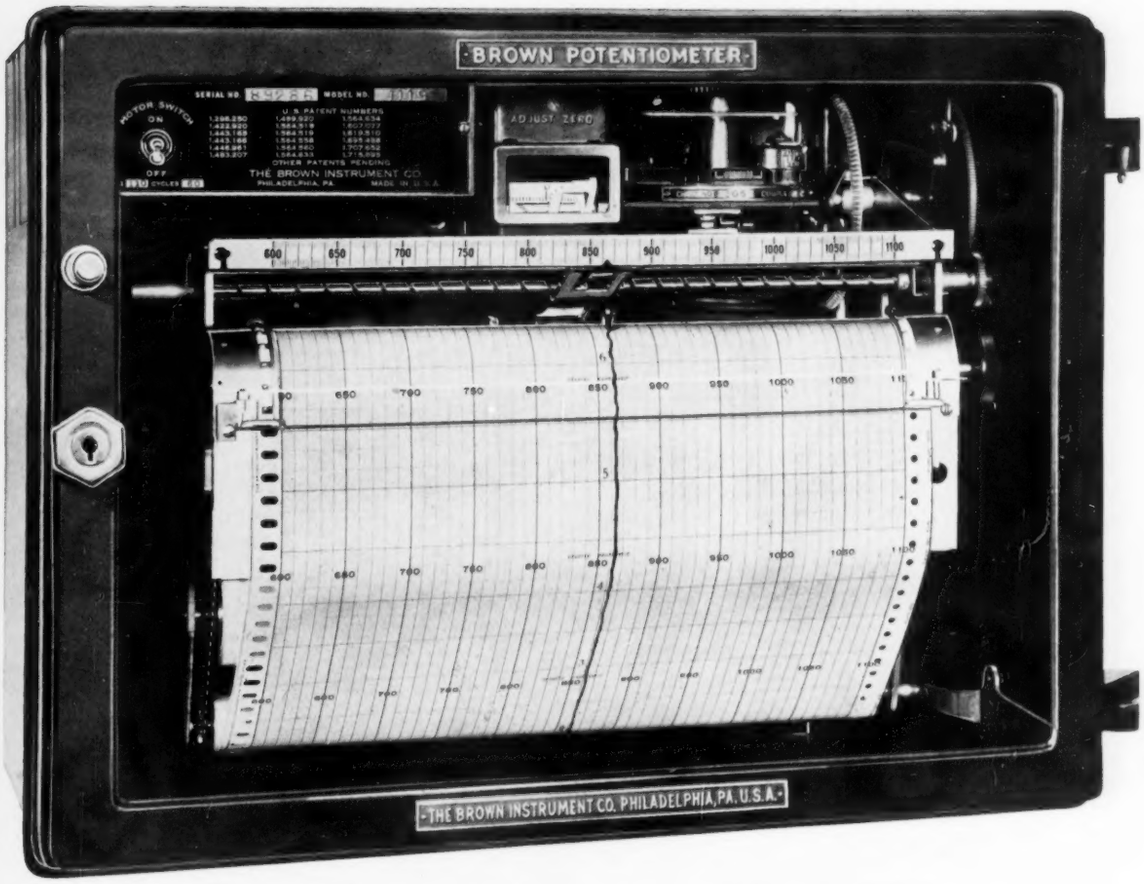

"Trendalizing" Quickly *STOPS* Overshooting —then *PREVENTS* Undershooting!

WHAT happens when your control temperatures suddenly rise above the control point? Does your controller let them swing widely—then over-adjust the control valve so that the temperature drops below the control point?

This wasteful overshooting and undershooting is eliminated by the Brown "Trendalizer." At the first indication of a temperature change the Trendalizer opens the valve to slow down the change, following that temperature trend like a shadow until its direction is reversed. When the temperature begins dropping back toward the control point, the Trendalizer subtracts just enough of the previous valve movement to balance the new heat demand and return the temperature to the control point without undershooting.

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The uses for "Autosyn" are wide and varied in practically every industry where remote indications are desired. Because of its unigue design and positive-action characteristics, Autosyn will respond to the slightest variances. A precisely balanced low-weight rotor, provided with ball bearings permits the operations of Autosyn by a very low torque. Delicate movements of sensitive elements, such as bellows or bourdon tubes, may be instantly transmitted to duplicate or triplicate indicators • Our Engineering Department will gladly cooperate with you in solving your remote-reading problems. Write for complete description and information of Autosyn.

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EDITORIAL COMMENT

In This Issue

◆ By a sad coincidence, the author of the first notable report on orifice coefficients passed away as the authors of the latest report were giving it a final revision before mailing it to us. An obituary of **J. M. Spitzglass** appears on page 208. The work he began is being carried on by capable physicists and engineers. **Professor Tuve** has long specialized in fluid flow and heat transfer. He built up the Texas Technological College laboratories and served as experimental engineer for a public service company before coming to Case. **R. E. Sprenkle** joined the Bailey Meter Co. after serving in the Signal Corps in 1917-19, and since 1922 his duties have consisted of research in fluid flow.

◆ The long chapter on positive meters in our Flow handbook concludes this month with wet types of gas meters.

◆ Fewer than the last few months' average, the **New Instruments** nevertheless evidence by their variety an unconquerable striving for more accurate and more convenient methods in all fields of measurement and control.

◈ ◈ ◈

Next Month

◆ Something will have to be done about the modesty of designers of automatic control systems. Take **Eric Pick, M.E.**, for example: if we weren't neighbors and friends, his new control valve, rate-of-flow devices, timers and associated devices—eliminating manual control from a well-known chemical process—might never have been reported in this magazine. Fortunately, he has prepared an interesting illustrated description which will appear in our next issue. But **Eric** is only one of the many reticent violets of Instrumentation. Readers knowing any of them are asked to urge them to announce their achievements through our hospitable pages. Your editor is losing sleep worrying about these untold stories of Measurement and Control. See what *you* can do. Anyway, we have a great article by **Pick** for December.

◈ ◈ ◈

The Front Cover

◆ Two schools of opinion regarding switchboards provide interesting discussions. One advocates the enclosed dead-front type—vast surfaces broken only by little levers; the other upholds the open type "where you can *see* the devices you rely on." In our opinion, the question whether the breakers and other mechanisms should be accessible or concealed is less important than the need of having plenty of indicators to keep attendants informed, enough graphics to provide permanent records for the higher-ups, and meters registering the energy in all circuits for the benefit of all concerned. Our front cover shows a switchboard built by the Roller-Smith Co. for the city of Tecumseh, Neb. We call it modern because of the rectangular instruments, because of the graphics and because the energy in all main circuits is metered.

"Juice"

The uses of electrical energy in industry may be classified as follows:

(1) *Processing conditions*: such as electric furnaces, electrolytic processes, electric welding, and the precipitation of finely divided solids from gases.

(2) *Motive power*: the driving of conveyors, elevators, rolling mills, machine tools and numerous specialized forms of textile, rubber, paper, tobacco, chemical, wood-working, ceramics, plastics and food-products machinery; to which service is related—

(3) *Measurement of non-electrical magnitudes*, such as temperature, flow, pressure, speed, chemical conditions, etc.

(4) *Manual and automatic control of conditions*, including the remote operation and control of valves, dampers, etc., the automatic regulation of temperatures, pressures, speeds and chemical conditions.

(5) *Illumination*: the general and special lighting of the plant.

(6) *Communication and signaling*, including bells, pilot lights, telephones, remote indicators, etc.

(7) *Safety*: from the simplest cut-out to the most elaborate interlock circuit.

The problems of electrical measurement, however, confront us not only in the above-mentioned aspects of the utilization of electrical energy, but to an even greater degree in the power house and on the circuits through which the electric current is made available to industry.

Electrical instruments thus have manifold duties to perform. In some instances they appear only as indicators, giving the user an idea of the value of the magnitude with which he is dealing, in other cases as recorders, providing a permanent record of energy consumption or of the performance of some unit of the plant. Electrical instruments are often essential to the successful operation of mechanical units; and to those responsible for the supply of electric power to industry and commerce, electrical measuring devices become the cash registers of the system and establish the revenues of the great electrical utilities. It therefore follows that not only is there a variety of electrical magnitudes to be determined, but that the system of measurement and the required precision must vary greatly under differing conditions.

THUS begins the first chapter of a new book on electrical measurements and control for industrial users of electrical energy and for all users of electrical instruments and devices in general. The publisher takes great pleasure in announcing that the serial publication of this handbook will begin in the January 1934 number of *Instruments*. Each monthly instalment will not only be informative but it will grip your attention and leave you, when you have finished it, with the satisfaction of having absorbed and digested a well-balanced meal.

The reason the publisher is able to promise all this with such confidence is because he knows the two authors of this book, because he has examined much of the book itself, and because this book is Part Seven of Béhar's Manual of Instrumentation. One of the two authors, therefore, is Major Béhar, who needs no introduction to our readers, having been for three years engineering editor, and this past year editor of this magazine. The first six Parts of his Manual have been running serially in these pages for nearly four years. Back in 1928 his idea was to write only one chapter on electrical instruments and meters, but after associating himself with the publisher of *Instruments* he came to the conclusion that the subject deserved a complete and modernized handbook treatment from the industrial angle. He and the publisher searched for an outstanding electrical specialist in electrical measurement and we had the good fortune to enlist the services of Perry A. Borden, eminent electrical engineer whose achievements with the Hydro-Electric Commission of Ontario, in the A.I.E.E. and elsewhere are historic.

With Mr. Borden as co-author, the Handbook of Industrial Electrical Measurements and Control rapidly took shape and is now being perfected into a unique treatise for which there is a crying need.

The publisher begs to close this announcement with a request to each reader to call it to the attention of all acquaintances who have to do with industrial electricity. By getting them to subscribe, you will be doing every one of them a real favor.

Richard Rimbach

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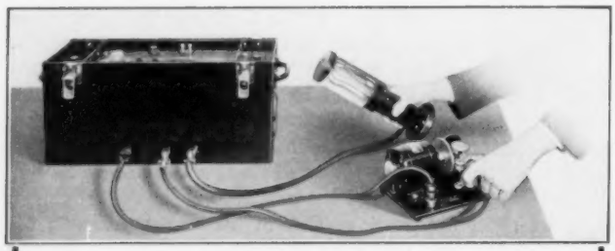

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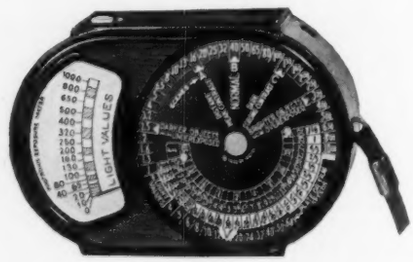


WESTON *Instruments*

Orifice Discharge Coefficients for VISCOUS LIQUIDS

By G. L. TUVE* and R. E. SPRENKLE**

ENGINEERING problems in connection with oil-fired furnaces and with chemical processes call for accurate metering of viscous liquids. The results of three years' research on this subject are reported, and practical applications described.—Editor

INTRODUCTION AND PURPOSE

THE convenience and simplicity of the thin plate orifice meter encourage its use for measuring the flow of viscous homogeneous liquids in small pipes. A typical application is the supply to an oil burner serving a metallurgical, industrial or boiler furnace, where accurate fuel measurement facilitates proper control of operating conditions. That such applications have not been made in appreciable numbers in the past is due to inadequate knowledge not only of orifice characteristics in the viscous flow range, but also of the proper method of accounting for the effect of viscosity. Moreover, there has been some doubt as to what type of orifice assembly would prove most reliable in the measurement of oil and other liquids of high viscosity. As a means of accumulating a working knowledge of the performance of thin plate orifices under these conditions, a cooperative research project was initiated three years ago by the Case School of Applied Science and the Bailey Meter Company. As a result of this experimental study the authors propose to offer in this paper the following:

1. A progress report covering the results of more than 500 experimental determinations of orifice coefficients in the viscous, the critical and the lower turbulent ranges, which have been made at Case School of Applied Science. In these determinations, eight sizes of orifices were used, with liquids in the range of viscosity between that of water and that of lubricating oil of 7500 seconds Saybolt.

2. A comparison of all orifice data now available on the low Reynolds number range and a discussion of the present status of the viscous flow problem.

3. A further discussion of the advantages and shortcomings of the Reynolds number as a basis for correlating data.

SUMMARY OF RESULTS AND CONCLUSIONS

The general conclusions from these studies are briefly as follows:

1. Orifice coefficients for the entire range of viscous, critical and lower turbulent flows may be correlated satisfactorily on the basis of Reynolds numbers, as shown in the composite curves of Fig. 1.

2. Throughout this entire range, the orifice coefficients were reproducible for the same operating conditions.

3. Orifices of diameter ratios up to 50% are satisfactory for viscous, critical and turbulent flow measurement of homogeneous liquids, provided that the Reynolds number expressing the flow conditions is not less than 100. For Reynolds numbers below 100, the orifice is a possible metering element, but it is not recommended, see Fig. 1.

4. The general characteristics of orifices of diameter ratios exceeding 50% are fairly well defined by the curves of Fig. 1, but in view of the extreme slope of these curves—indicating the instability of the orifice coefficients for small changes in viscosity, temperature, or density—these larger orifices cannot be recommended for commercial use.

5. For orifice assemblies with essential features of design as shown in Fig. 2, the coefficients for the recommended ranges are shown in Fig. 3. These coefficients apply with an accuracy of $\pm 1\frac{1}{2}\%$ to both corner and to vena contracta pressure connections, provided the vena contracta outlet connection is placed at 0.3 pipe diameters beyond the face of the orifice. The coefficients may be obtained directly from Fig. 3 if rate of flow, pipe size, orifice ratio and viscosity are known.

RECOMMENDATIONS FOR FURTHER STUDIES

To obtain a complete and accurate set of coefficient curves for the viscous and turbulent ranges is a very large job and one which is far from being completed at the present time. Perhaps the most practical work which could be undertaken next would be the determination of effect of pipe size and finish upon the coefficients of orifices of diameter ratios from 20 to 50% inclusive, at Reynolds numbers above 100. It is quite evident that before additional work in the viscous flow region is attempted, it would be advisable to adopt a standard form of orifice assembly. The authors feel that the type shown in Fig. 2 is entirely

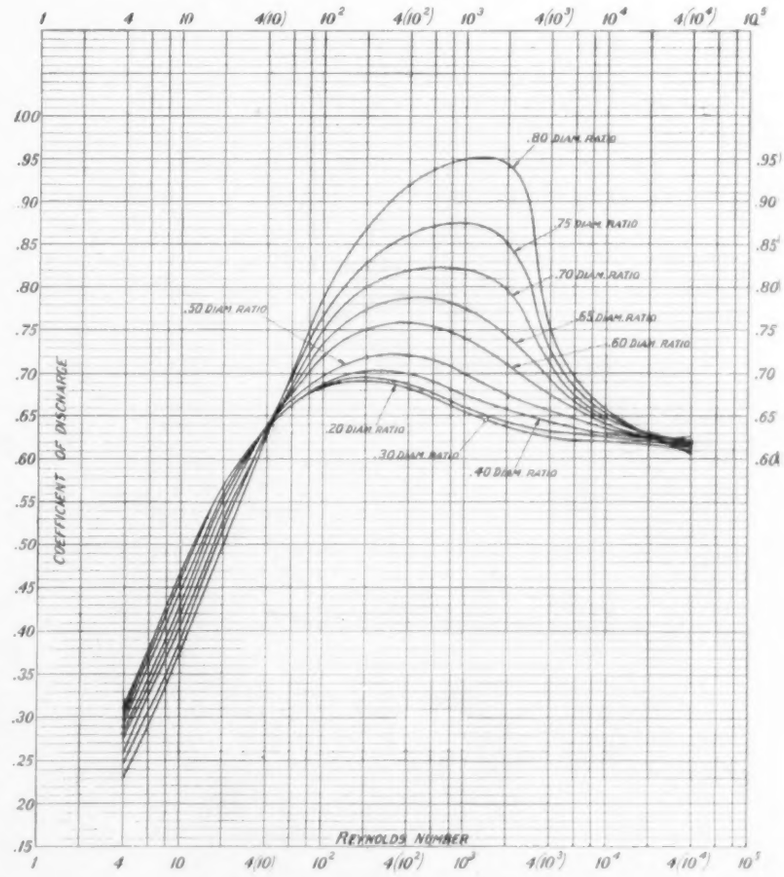


Fig. 1. Composite Orifice Coefficient Curves for Viscous Liquids.

*Associate Professor of Mechanical Engineering, Case School of Applied Science, Cleveland, Ohio.
**Mechanical Engineer, Bailey Meter Co., Cleveland, Ohio.

To be presented at the session of the A.S.M.E. Special Research Committee on Fluid Meters during the Annual Meeting of the American Society of Mechanical Engineers in New York, Dec. 4-8, 1933.

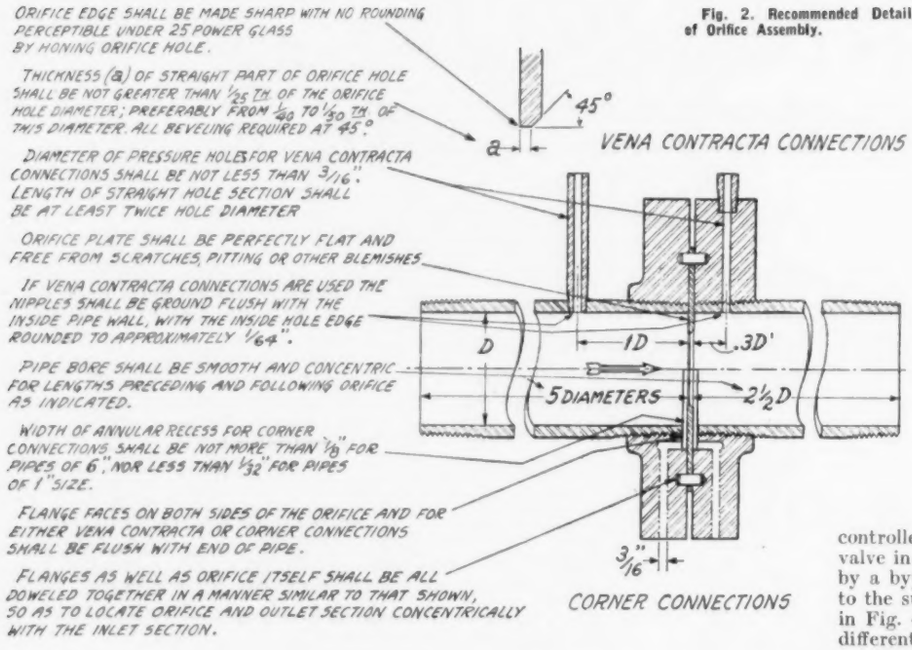

ORIFICE EDGE SHALL BE MADE SHARP WITH NO ROUNDING PERCEPTIBLE UNDER 25 POWER GLASS BY HONING ORIFICE HOLE.
THICKNESS (a) OF STRAIGHT PART OF ORIFICE HOLE SHALL BE NOT GREATER THAN 1/25 TH. OF THE ORIFICE HOLE DIAMETER; PREFERABLY FROM 1/60 TO 1/30 TH. OF THIS DIAMETER. ALL BEVELING REQUIRED AT 45°.
DIAMETER OF PRESSURE HOLES FOR VENA CONTRACTA CONNECTIONS SHALL BE NOT LESS THAN 3/16". LENGTH OF STRAIGHT HOLE SECTION SHALL BE AT LEAST TWICE HOLE DIAMETER
ORIFICE PLATE SHALL BE PERFECTLY FLAT AND FREE FROM SCRATCHES, PITTING OR OTHER BLEMISHES.
IF VENA CONTRACTA CONNECTIONS ARE USED THE NIPPLES SHALL BE GROUND FLUSH WITH THE INSIDE PIPE WALL, WITH THE INSIDE HOLE EDGE ROUNDED TO APPROXIMATELY 1/64".
PIPE BORE SHALL BE SMOOTH AND CONCENTRIC FOR LENGTHS PRECEDING AND FOLLOWING ORIFICE AS INDICATED.
WIDTH OF ANNULAR RECESS FOR CORNER CONNECTIONS SHALL BE NOT MORE THAN 1/8" FOR PIPES OF 6", NOR LESS THAN 1/32" FOR PIPES OF 1" SIZE.
FLANGE FACES ON BOTH SIDES OF THE ORIFICE AND FOR EITHER VENA CONTRACTA OR CORNER CONNECTIONS SHALL BE FLUSH WITH END OF PIPE.
FLANGES AS WELL AS ORIFICE ITSELF SHALL BE ALL DOWELED TOGETHER IN A MANNER SIMILAR TO THAT SHOWN, SO AS TO LOCATE ORIFICE AND OUTLET SECTION CONCENTRICALLY WITH THE INLET SECTION.
45°
a
VENA CONTRACTA CONNECTIONS
D
1D
.3D'
5 DIAMETERS
2½D
3/16"
CORNER CONNECTIONS

Fig. 2. Recommended Details of Orifice Assembly.

satisfactory, easy to construct and to maintain in a serviceable condition. Unless the essential design features shown in Fig. 2 are used, the coefficients of Fig. 3 do not necessarily apply on account of the uncertainty caused by such factors as the apparent disappearance of the vena contracta, the effects of orifice finish and edge width, and the effect of roughness of the approach section.

EXPERIMENTAL APPARATUS AND METHODS

Acknowledgment. The authors wish to acknowledge the work of Messrs. Cowles, Kartorie, Heisterkamp, Eger, Theiss and Slater in the experimental phase of this study. The present status of the project is due largely to the experimental work which they have carried out as a part of their thesis requirements at Case School of Applied Science.

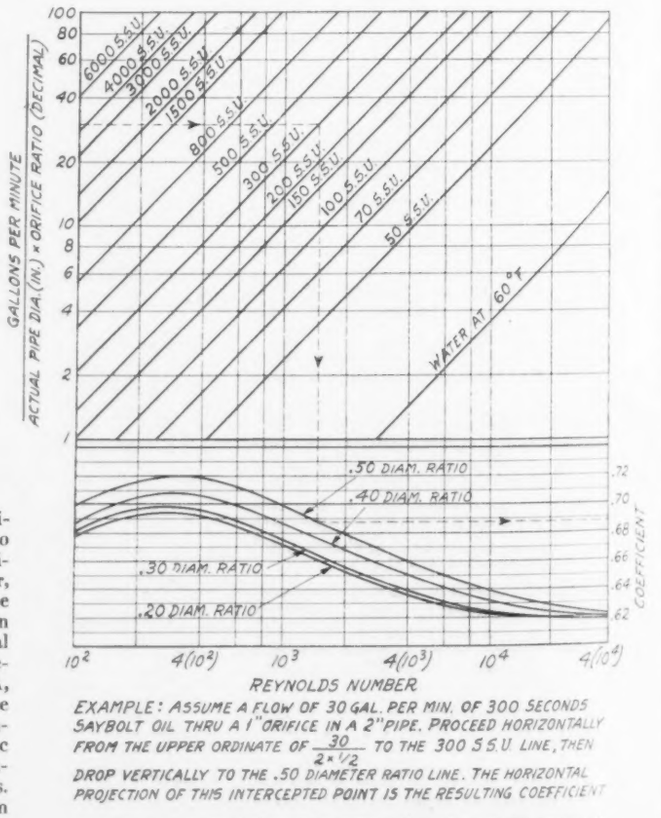
General Set-up. All data were obtained by means of the weigh-tank system shown in Fig. 4. The two weigh tanks were supported by calibrated scales sensitive to 0.1 lb. Discharge from these tanks was emptied into a sump through drains turned upward under the surface of the liquid in the sump. For water and the lighter oils, a centrifugal pump was used for recirculating the liquid, but a rotary (Viking) pump was required for the heavy oils. An air chamber was used with rotary pump but no pulsations could be detected without it. A shell-and-tube type of surface heat exchanger followed the pump and air chamber assembly, and this was piped for both heating and refrigeration. The approach pipe to the orifice assembly consisted of a section of extra-heavy smooth brass tubing 1.272" I.D. and 100 diameters long, with straightening vanes at the entrance. Open-end vertical manometers were used, the final set-up having three inlet and seven outlet indicating tubes, all ⅜" I.D. This number of tubes was used in order to study more carefully the point of minimum static pressure on the outlet side of the orifice as well as the point of maximum static pressure on the inlet side.

Orifices and Orifice Assembly. The orifice test section, essentially as in Fig. 2, was also of 1.272" I.D., finished smooth and so arranged that it could be taken apart readily for changing orifices. The pressure connections on the inlet side, two in number, were ⅛" brass pipe nipples ground flush and smooth with the inside of the tube. The outlet pressure connections, eight in number, terminated in 1/16" diameter holes arranged in a spiral row and spaced in tenths of a pipe diameter. Two annular recesses 1/16" x ⅜", each formed by a 1/16" gasket (see Section AA, Fig. 5), constituted the corner connections for measuring the differential across the faces of the orifice. Each recess communicated to a 3/16" hole in the flange face by which the static pressure was brought out to the manometer connections. Alignment of the test section and orifice was assured by dowel pins. All pressure connections terminated in clean holes free from burrs and with the hole edge rounded to approximately 1/64".

Twelve orifice plates were used, ten of Monel metal, one of brass and one of stainless steel, all 1/32" thick. All the Monel metal orifices were honed, the downstream faces being beveled at 45° to produce an orifice edge length of ⅛". Orifice edges were examined under a 25 power microscope after using and the flatness of the plate also checked. Duplicates were made of certain orifices.

Operation. Ample time (from 20 to 60 minutes) was allowed before each run to insure steady conditions, that is, constant heads and temperatures. Tests made under conditions which varied in the course of the test were rejected. No adjustments of the control valves were made during a run. The pumps were operated at constant speed and the flow was controlled by a large and a small throttle valve in parallel on the pump discharge and by a bypass valve returning the oil directly to the sump, all of which is shown in detail in Fig. 4. Most of the runs were made with differential heads between 5" and 60", the maximum range being 3" to 80"—all differentials being expressed in inches of flowing fluid. Special precautions were taken against air entrainment in the liquid. Continuous vents were provided at the inlet of the approach pipe and of the test section. Manometers were examined by transmitted light for air bubbles and whenever such bubbles appeared on the meniscus surface they were removed by connecting the open end of the tube to an ejector.

Observations. The duration of each run averaged 15 to 20 minutes with two observers taking simultaneous readings of the inlet and outlet manometers every half minute. Discharge was weighed in two 30-gallon tanks used alternately, and special piping was arranged to insure a minimum disturbance to flow conditions when changing discharge from one tank to the other.

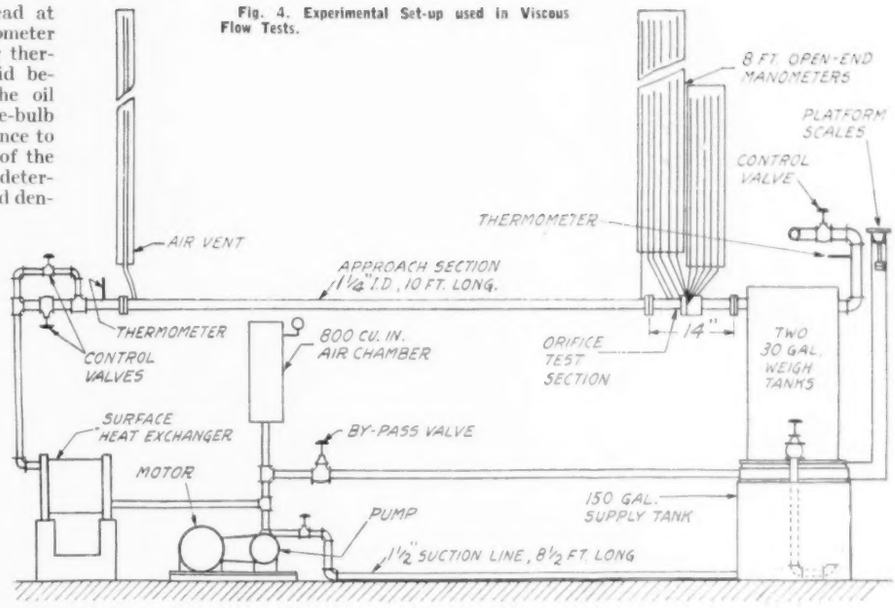


EXAMPLE: ASSUME A FLOW OF 30 GAL. PER MIN. OF 300 SECONDS SAYBOLT OIL THRU A 1" ORIFICE IN A 2" PIPE. PROCEED HORIZONTALLY FROM THE UPPER ORDINATE OF $\frac{30}{2 \times 1/2}$ TO THE 300 S.S.U. LINE, THEN DROP VERTICALLY TO THE .50 DIAMETER RATIO LINE. THE HORIZONTAL PROJECTION OF THIS INTERCEPTED POINT IS THE RESULTING COEFFICIENT

Fig. 3. Recommended Coefficients for Orifices of the design of Fig. 2.

Temperatures in the line were read at least every five minutes and manometer temperatures obtained by lowering thermometers into the indicating liquid before and after each test run. The oil temperatures were observed by bare-bulb mercury thermometers at the entrance to the approach pipe and at the exit of the test section. Oil viscosities were determined by a Saybolt viscosimeter, and densities by precision hydrometers.

Fig. 4. Experimental Set-up used in Viscous Flow Tests.



CALCULATIONS AND RESULTS

Computed Results. All calculations were made independently by two or more computers, using calculating machines. Corrections were made for the difference in density between the fluid in the line and that in the manometers. All of the computed results herewith presented are based on the common "hydraulic equation":

$$Q = Ca\sqrt{\frac{2gh}{1-(a/A)^2}} \quad \ldots (1)$$

While there may be some difference of opinion regarding the correctness of using this equation for the viscous region, an analysis of the data showed that no other simple equation, without a variable coefficient applies in this range. Moreover, all corresponding results presented by other investigators are calculated by the hydraulic equation. As the following paragraphs will show, the discharge coefficients calculated on this basis give smooth reproducible curves over the entire range needed in practice, and this enables the orifice meter to be used in either the viscous, the critical or the turbulent region without departure from the usual method of calculation.

Two complete sets of discharge coefficients were calculated, one based on the readings from the pressure connections at the orifice faces (hereafter called the "corner connections"), and the other based on the readings from the so-called "vena contracta" connections.

Graphical Presentation and Recommended Coefficients. Since the other investigators whose results are available have used corner connections only, the results of the authors' tests have been plotted on this basis in Fig. 6 and are presented for comparative purposes. Similar curves have been prepared for the so-called vena contracta connections and both groups have also been plotted on the square root scale of Reynolds number R_4 instead of the logarithmic scale, but these are not reproduced here for lack of space.

Accuracy and Reproducibility of Coefficients. An analysis was made of the deviation of test points from the average curves as shown. For the 550 tests, there was an average variation of but 0.6%, and only 10% of the tests varied from the curves by over 1.5%. Various additional tests were made to determine the reproducibility of the coefficients for duplicate determinations and also for variations in the design and operating conditions. More than fifty pairs of experimental tests with dissimilar conditions of velocity and viscosity, but with the same Reynolds number, have been produced and compared, and a few of these are listed in Table 1. It will be seen from this table that although the second test point of each pair represents an increase in most cases of over 50% in the differential head, the average difference in the coefficients of discharge is less than 1%. A comparison may be made with Table 2 which gives differences in coefficients for nearly identical conditions of velocity and viscosity for each pair. These tables show that the reproducibility of coefficients at any given Reynolds number is about as good with unlike as with like values of velocity and viscosity. This indicates the validity of the Reynolds number criterion.

In the matter of design variations, additional tests were run with different orifices, with a different approach pipe, and with a different orifice test section. Fifteen runs in the Reynolds number range between 30 and 1000, with each of two additional orifices of the 40% ratio size, showed an agreement within 1% of the standard 40% orifice. Similarly twenty-five check runs with the 40% orifice, in the Reynolds number range of 100 to 1000, using a commercial extra-heavy black steel approach pipe preceding the orifice test section, gave coefficients within 1% of those obtained with the standard set-up.

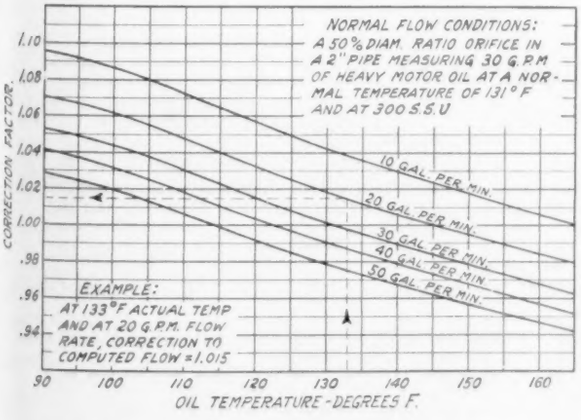


Fig. 5. Example of Correction Factors for Variations in Viscosity, Density and Flow Rate.

COMMERCIAL USE

For practical use, at this time, the authors recommend only the range of diameter ratios from 20% to 50% inclusive, and Reynolds numbers above 100. In this range the coefficients for the two sets of pressure connections were found in these tests to agree within a fraction of 1%. Therefore the curves of the lower part of Fig. 3, which give the recommended coefficients, may be used for either type of pressure connection provided the requirements listed on Fig. 2 are followed. For these conditions the accuracy of this set of coefficients is within 1.5%.

The authors realize the lack of available curves or other means for readily converting given flow conditions into terms of equivalent Reynolds numbers for purposes of design and use. At the top of Fig. 3 are therefore placed a series of diagonal lines representing a range of viscosity from 50 to 6000 seconds Saybolt and covering the Reynolds numbers above 100, as recommended. To use these it is only necessary to make a tentative selection of pipe size and orifice ratio for the rate of flow under consideration, and to calculate the product:

$$\frac{\text{Gal. per min.}}{\text{Actual pipe I.D. (in.)} \times d/D} \quad \ldots (2)$$

Locating this number on the upper ordinate scale, crossing horizontally to the viscosity line and dropping vertically to the curve for the orifice ratio, the coefficient may be read on the lower ordinate scale (see Example on Fig. 3). Any intermediate

Table 1 COMPARISON OF DISCHARGE COEFFICIENTS FOR LIKE REYNOLDS NUMBERS OBTAINED BY UNLIKE CONDITIONS USING CORNER CONNECTIONS

Diameter Ratio, %	Reynolds Number	Viscosity of Oil, Saybolt Seconds	Differential Head in. flowing fluid	Increase in Differential Head %	Coefficient of Discharge	Difference in Coefficients, %
20	15.7	3250	20.3	66.	0.5379	0.86
20	15.9	4020	33.7		0.5333	
30	16.9	3700	13.1	66.	0.5513	1.12
30	17.7	4850	21.8		0.5575	
30	57.6	2180	36.8	29.	0.6549	0.24
30	56.7	2500	47.3		0.6565	
30	146	680	19.5	20.	0.6923	0.30
30	143	760	23.5		0.6944	
30	1590	50	7.4	415.	0.665	0.91
30	1435	91	38.1		0.659	
40	78.9	2080	33.8	50.	0.6752	0.0
40	77.1	2610	50.8		0.6751	
40	452	255	23.2	21.	0.698	0.72
40	460	310	28.8		0.703	
50	68.4	2350	19.2	48.	0.6784	0.24
50	66.2	3000	28.4		0.6801	
70	1298	179	10.2	142.	0.819	0.0
70	1303	248	24.7		0.819	
80	5360	53	7.7	60.	0.694	1.41
80	5440	68	12.3		0.704	

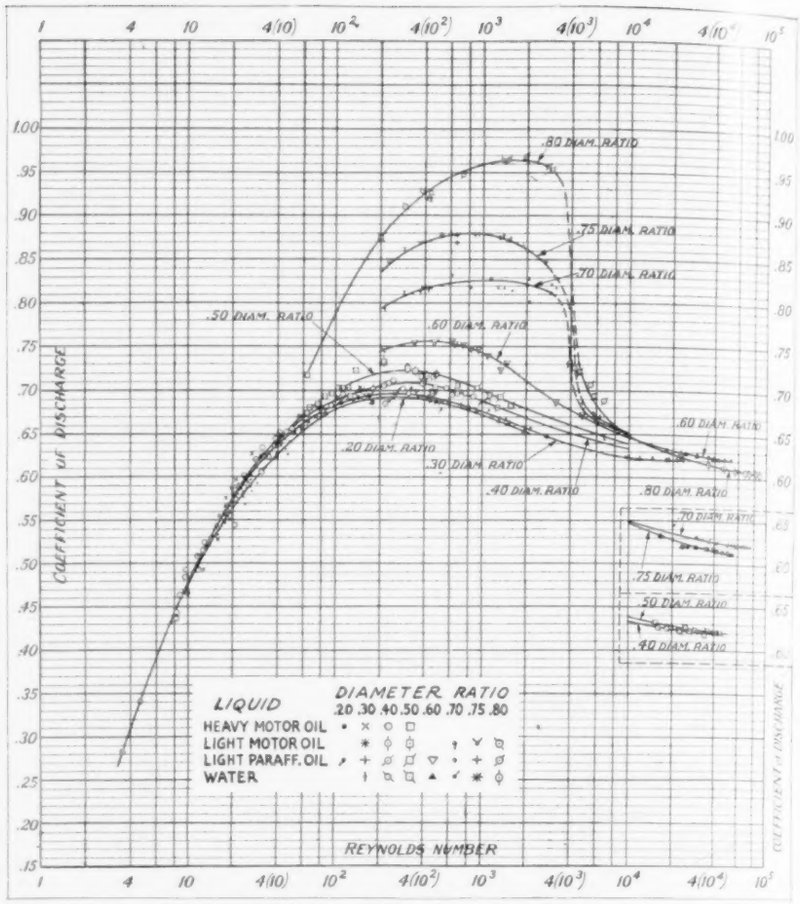


Fig. 6. Experimental Results of Viscous Flow Tests—Corner Connections.

viscosity or diameter ratio may be located with sufficient accuracy by interpolation.

By substituting this value, together with the pipe size and the quantity rate desired, in the flow equation (1), the resulting differential in terms of h is obtained. Should this be found too high or too small to suit the range of either the manometer or meter available it will be necessary to change either (A) the pipe size, (B) the diameter ratio, (C) the desired maximum capacity, or (D) the viscosity. This latter factor can usually be so modified by heating the oil at the point of metering.

In commercial applications where the temperature varies somewhat and cannot be compensated for in the meter calibration, the recommended range of orifice ratios and Reynolds numbers has a special advantage by reason of the comparative flatness of the coefficient curves. A typical example of the corrections required to compensate for variations in viscosity and density, due to temperature changes, is shown in Fig. 5. These correction factors, when applied to either the computed Q in equation (1), as based on the standard conditions shown on the figure, or when applied to the meter constant, give the corrected flow under the actual conditions. Similar curves are also given to show the required corrections for variations in the flow rate, not only at the standard but also at other temperatures.

CORRELATION OF VISCOUS FLOW ORIFICE COEFFICIENTS

It is realized that no work of this nature serves its maximum usefulness until compared in detail with the work of other experimenters. Such comparisons immediately disclose important discrepancies in the work being done, or lend confidence in the results obtained if a good agreement be shown. In making these comparisons, however, the data of each experimenter must be evaluated in accordance with the similarity requirements discussed in the next section.

At the outset of these tests an examination of the existing literature on this subject showed that there was at least one important point of similarity in all the work performed so far, namely, the use of corner differential pressure connections. These connections were taken at the *faces* of the orifice plate, in most cases by providing annuli between the orifice plate and the holding flanges, and always so as to communicate the static pressures on both faces of the orifice to the test manometer. Inasmuch as details of these arrangements are given in the papers of each of the investigators cited, no attempt is made to reproduce them. However, in order that a suitable comparison could be made with these data, the authors used both corner connections and the so-called vena contracta type which are favored in this country.

In brief, the data available embraced the work of six investigators working in England, Germany and the United States, using eight different pipe diameters ranging from $\frac{5}{16}$" to 4" I.D., using water, water-glycerine mixture and at least six different grades of oil. The salient points pertaining to the work of each experimenter are as follows:

The work done by Johansen in England[1], and as given in the Aeronautical Research Committee report, more completely covers the entire viscous flow range than does any other. The five orifice diameter ratios used in these tests were 0.09, 0.209, 0.401, 0.595 and 0.794. The orifice assembly was somewhat similar to that used by the authors in their tests in respect to the use of the corner connections but, of course, did not have vena contracta or any other type of differential pressure taps. All of Johansen's water flow calibrations were made with the orifices installed in pipes having an internal diameter of approximately 1¼". However, the oil flow tests in the viscous range were made with pipes of 0.301" I.D. Reference to the five curves in Fig. 6 of his paper will show a complete continuity in the joining of the water and the oil curves, indicating no difference in coefficient due to change in pipe diameter. This is at variance with what would be expected from previous work in the turbulent flow region reported by Spitzglass[2] and by the A.S.M.E. Fluid Meter Report, Part 1, and from work most recently done at Ohio State University by S. R. Beitler[3] under the direction of the A.S.M.E.-A.G.A. Joint Orifice Committee. For all practical purposes, Johansen had but four different size orifices as the smallest, namely the 0.09 pipe diameter ratio, was calibrated only to a maximum Reynolds value of 50.

Witte's viscous flow tests[4] for the I. G. Dye Industries in

[1]F. C. Johansen. "Flow through Pipe Orifices at Low Reynolds Numbers." Reports and Memoranda No. 1252 of the Aeronautical Research Committee, London, England, June 1929.

[2]J. M. Spitzglass, "Orifice Coefficients—Data and Results of Tests." *A.S.M.E. Transactions*, Vol. 44, 1922, pages 919 to 974.

[3]S. R. Beitler. "Determination of Discharge Coefficients of Sharp Edged Orifices in Pipes of from 1" to 14" in Diameter." A.S.M.E. Annual Meeting 1933.

[4]R. Witte. "Flow Constants of the I. G. Measuring Devices for

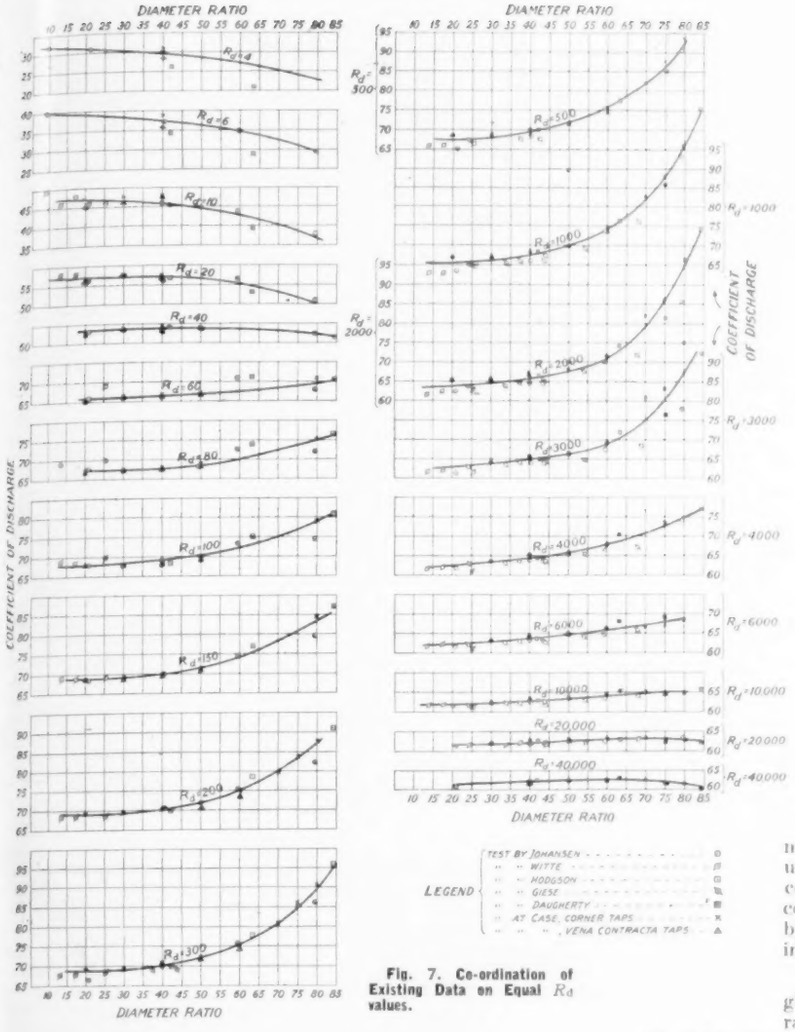


Fig. 7. Co-ordination of Existing Data on Equal R_d values.

Table 2 COMPARISON OF DISCHARGE COEFFICIENTS FOR LIKE REYNOLDS NUMBERS OBTAINED BY NEARLY IDENTICAL CONDITIONS USING CORNER CONNECTIONS

Diameter Ratio, %	Reynolds Number	Viscosity of Oil, Saybolt Seconds	Differential Head in flowing fluid	Coefficient of Discharge	Difference in Coefficients, %
20	21.7	4640	68.0	0.578	0.5
20	21.6	4640	67.0	0.581	
20	382	218	32.4	0.693	0.0
20	381	229	35.6	0.693	
30	18.1	4500	21.0	0.565	1.2
30	17.7	4650	21.7	0.558	
30	44.7	2620	5.76	0.645	0.2
30	45.9	2620	5.92	0.646	
30	71.4	2230	7.5	0.667	0.4
30	73.5	2230	8.1	0.670	
30	143	535	4.12	0.695	0.3
30	147	478	4.07	0.697	
30	242	500	29.2	0.690	0.9
30	250	480	28.7	0.696	
40	12.5	6030	3.57	0.516	0.2
40	12.7	6000	3.55	0.517	
40	61.8	2750	5.8	0.662	0.3
40	61.9	2700	5.8	0.664	
50	75.1	2210	20.3	0.684	0.2
50	73.1	2150	18.2	0.685	
50	106	1930	5.28	0.702	0.1
50	108	1900	5.33	0.703	
70	8357	51	23.9	0.655	0.5
70	8124	52	27.4	0.652	
80	415	567	6.4	0.920	0.7
80	422	536	6.2	0.926	
80	2955	70	5.5	0.822	0.6
80	3165	67	5.5	0.817	

Germany in 1928 included in all seven orifices of diameter ratios of 0.243, 0.339, and 0.438 in a 3.94″ I.D. pipe, and ratios of 0.370, 0.44, 0.542 and 0.68 in a 1.97″ I.D. pipe. These tests, however, extended down to a minimum Reynolds number of approximately 300 based on orifice throat diameter and speed and therefore, are incomplete in the extremely viscous regions. Again, no marked difference in coefficients was discovered in the 2″ and the 4″ pipe-size orifices. As compared with the orifice assemblies used by other experimenters, the I.G. type of orifice is perhaps the most dissimilar. Notwithstanding this, it is interesting to note that his data agree quite closely with those of Johansen.

Hodgson's data[5] are perhaps the oldest but cover only three diameter ratios, namely, 0.421, 0.632, and 0.841. In fact these are the same orifice installed in three different lines of 0.755″, 0.503″ and 0.378″ I.D. pipe respectively. The orifice carrier used by Hodgson (as shown in Fig. 5 in the 1929 A.S.M.E. paper) has the corner pressure connection arrangement somewhat similar to that used by Johansen and in the authors' experiments. His results line up more nearly with those obtained by the authors than do either Johansen's or Witte's.

Giese[6] is the latest experimenter to present data in the viscous flow region. A great portion of his work covers specially shaped orifices, standard orifices with the beveling reversed and extremely thin plate orifices. Three of his orifices, however, were of appreciable thickness, that is, approximately $\frac{3}{16}$″, beveled to 45°, and only the calibrations obtained therefrom are included in this analysis. These orifices were of the 0.137, 0.176 and 0.258 diameter ratios, all tests having been made in 1.575″ I.D. pipe. The orifices were all used in special holding flanges having pressure connections so arranged as to be generally comparable with the corner connections used by both Johansen and the authors, but differing considerably in detail construction.

None of the investigators referred to above gives sufficient data to indicate the actual ranges of differential pressures utilized across the orifice or the range of viscosities of the various liquids used. Thus, these analyses must assume the ranges to be substantially those used by the present authors; at least, no cognizance can be taken of any specific differences therefrom.

The graphic method of comparison was used in co-ordinating the data given by these several investigators with those obtained by the authors. The procedure was as follows: At any one value of Reynolds number, based on orifice throat diameter, the corresponding coefficient was taken from the curve of each experimenter for each orifice tested. These values were plotted on the basis of orifice diameter ratio versus orifice coefficient and a smooth curve then drawn through these points. In all, twenty values of the Reynolds number were chosen for this plotting, and the curves are shown in Fig. 7. From each of these curves, points were taken for the various diameter ratios and these in turn were replotted on the basis of Reynolds numbers versus the orifice coefficient. By connecting like points for each diameter ratio on the 20 different Reynolds numbers and by cross-plotting to iron out small irregularities, a family of coefficient curves was obtained as shown in Fig. 1.

Referring to Fig. 7 it will be noted that appearing thereon are not only the coefficients for corner connections from the authors' tests but also coefficients for the so-called vena contracta connections. It is interesting to note the close agreement between these two sets of pressure connections for all Reynolds numbers of approximately 150 and above for orifices of diameter ratio up to 50%. This same close agreement between these two sets of pressure connections in the turbulent flow region has also been noted in the recent tests at Ohio State University[3] referred to above.

The curves in Fig. 7 were so drawn as to represent what appeared to be the best interpretation of the value of all the data considered. It will be noted that in all cases where a spread occurs between the coefficients for similar size orifices as used by different experimenters, the data by the authors appear higher, whereas those by Witte, Johansen and in several cases those by Giese appear lower than the average curve.

Water, Oil, Gas and Steam," from Physical Laboratory of the I. G. Dye Industries Corporation, Germany, 1928, see also *Zeitschrift V. D. I.* 1928, pages 1493 to 1502.

[5]J. L. Hodgson. "The Laws of Similarity of Orifice and Nozzle Flows." *A.S.M.E. Transactions,* Vol. 51, 1929, FSP 51-42, pages 303 to 332.

[6]H. G. Giese. "Flow Measurement with Nozzles and Orifices at the Low Values of the Reynolds Number." *Forschung,* 4, 11, 20 (1933).

The authors suspect that these differences are due mainly to lack of similarity which includes such variables as orifice edge finish, orifice edge width, beveling, pipe diameter or the roughness factor, size of annulus on each side of the orifice plate, and character of inlet and outlet pipe. These variations show a need for standardization of design so that future data will be on a more comparable basis than is the case at present.

ADVANTAGES AND SHORTCOMINGS OF THE REYNOLDS NUMBERS AS THE BASIS FOR CORRELATION

In the discussion which follows, a steady non-pulsating and non-helical flow is assumed and heat transfer and compressibility are considered negligible. Corrections for velocity of approach (initial kinetic energy of the stream) are made by the usual "meter constants."

The accuracy of any metering orifice when it is used without special calibration of the unit in place depends upon the similarity between its performance and that of some other standard metering unit for which the calibration is known. For perfect similarity in performance three groups of conditions must conform to those of the calibration standard:

1. The metering elements must be similar in geometrical design.
2. The flow patterns or stream characteristics of the fluid adjacent to the orifice must be similar.
3. The properties of the fluid being measured must be accounted for.

Certain of these similarity requirements have long been understood. For example, there has been no question as to the necessity of comparing the orifice in service with a standard of the same diameter ratio. It has further been known that since standard orifice calibrations are made under "steady" conditions, the flow pattern or stream characteristics in the vicinity of the orifice being compared must also be steady and continuous, with the net average motion of each particle in the axial direction only. As regards the fluid properties, cognizance has been taken of the difference in density between the fluid being metered and the fluid used in the orifice calibrations. However, it has not been generally understood that perfect similarity in the geometrical design of the metering element includes such details as relative pipe roughness, orifice edge finish, length of orifice tube or edge width, diameter of the pressure openings or holes, and length of straight approach and discharge sections. Likewise similarity of flow patterns means not merely freedom from swirls, pulsations or other irregularities but a similar placement of the fluid flow in either the viscous, critical or turbulent regions. Further the fluid properties to be accounted for include relative viscosity as well as relative density.

The idea is gradually being accepted that the dimensionless ratio known as Reynolds number fully defines the conditions necessary for similarity between any two fluid flow systems, when only the viscous and the inertia forces are acting.[7-10] For an orifice, the Reynolds number is expressed as:

$$R_d = \frac{V d \rho}{\mu} \quad \ldots\ldots\ldots \quad (3)$$

That is, in the case of two similarly sized orifices, if the axial velocity, density and absolute viscosity were the same and the orifices were in perfect geometrical agreement in design and installation, their coefficients should be identical. At first glance this seems to present an infinite number of possibilities of variation in actual operating conditions. Fortunately experiments have shown that there is an inter-relation of these variables in such a way that *any combination* resulting in the same numerical value of the Reynolds number, produces the same coefficient. Thus the individual values of V, d, ρ and μ may change, but if the Reynolds number is not changed, the same coefficient will hold. This is illustrated in the data given in Table 1 where conditions of velocity and viscosity varied appreciably, but so long as their ratio gave the same Reynolds number, the same coefficient of discharge was found. This result may be anticipated by a dimensional analysis,[11] and it is also in accord with experimental results in other fields of fluid dynamics such as friction in pipes and behavior of airplane models.

The physical requirements suggested by each of these factors and the significance of each in relation to the discharge coefficients, are somewhat as follows:

Linear Dimension "d." If a single linear dimension d is to represent the size of the entire metering element, strict geometrical similarity must be maintained in all respects. This means for instance that if orifices of various sizes are used in the same pipe, a different calibration curve will apply to each or that if the identical orifice plate is used in pipes of different sizes, the calibration curve for this orifice will change.

Axial Velocity V. It is convenient to use for d the measured orifice diameter and for V the measured volume of discharge divided by the area corresponding to d. This assumes a strict similarity of flow pattern, both preceding and following the orifice, especially with respect to jet contraction. It is well known that the velocity distribution across the inlet section and the size of the vena contracta of the discharge section vary with the axial velocity. It must then be expected that the coefficient of discharge will vary with velocity.

The Kinematic Viscosity of the Fluid μ/ρ. Absolute viscosity may be calculated with sufficient accuracy from measurements by a viscosimeter. Density may be measured by precision hydrometers or specific gravity balance. This assumes that accurate fluid temperature measurements are made during the metering process. Considering the fluid in motion at a definite average axial velocity, the density of the fluid fixes the magnitude of the inertia forces and the absolute viscosity fixes the magnitude of the viscous forces. Since these two forces determine the friction, the turbulence and the jet contraction, they must affect the value of the coefficient of discharge. As long as compressibility and heat transfer are negligible, the kinematic viscosity fully defines the properties of the fluid at a given temperature.

If all of the above requirements could be fulfilled in their entirety, the Reynolds number would be a perfect criterion as to the value of the coefficient of discharge for any combination of the variables of velocity, density, orifice size and viscosity. But while it is entirely possible to obtain a perfect criterion based on these variables, it is extremely difficult, if not impossible, to obtain perfect geometrical similarity in the orifice section itself. For example it is well nigh impossible to reproduce relative roughness, relative orifice edge finish or orifice plate finish exactly to scale, or to effect complete proportionality between the orifice edge width and orifice diameter. Of these details the relative roughness of the pipe wall itself probably offers the largest obstacle to the attainment of perfect geometrical similarity.

The experiments to date indicate* that the variation of coefficient with pipe size (which is another way of expressing relative roughness) is less pronounced in the viscous range than it is in the turbulent range. For the explanation of this it probably is necessary to go beyond the ideas expressed by the Reynolds criterion and to examine the magnitude of the pipe surface irregularities with respect to the pipe diameter. The same phenomenon appears in the results of pipe friction studies.[12,13,14]

Whatever the reasons, the fact remains that due to failure to obtain complete similarity in design, it is not possible to use the Reynolds number as a *complete* basis without incorporating some additional factor or set of tolerance limits to compensate for this failure to attain complete similarity. Since the variation of orifice coefficients due to pipe size, orifice edge finish and other factors which probably violate perfect similarity does not exceed 1½% in the turbulent region, the authors feel that in view of the present experimental evidence this tolerance is ample in the viscous and critical flow regions. Therefore, the data given in this paper can be correlated on the basis of Reynolds number within an accuracy of ± 1½% and used for commercial applications within this tolerance, when the orifice installation fulfills the design requirements of Fig. 2.

NOTATION

A = Area of pipe, square feet
a = Area of orifice, square feet
C = Coefficient of discharge (without velocity of approach)
D = Diameter of pipe, feet
d = Diameter of orifice, feet
g = Acceleration of gravity, ft./sec./sec.
h = Differential head in feet of flowing fluid
Q = Quantity rate of flow, cu ft./sec.
R_d = Reynolds Number, based on orifice hole diameter and velocity, consistent English units
μ = Absolute viscosity, lb./sec. ft.
V = Velocity through orifice, feet/sec.
ρ = Density of liquid at orifice, lb./cu. ft.

[7] O. G. Teitjens. "The Use of Models in Aerodynamics and Hydrodynamics," A.S.M.E. *Transactions*, Vol. 54, 1932, APM 54-22, pages 225 to 233.

[8] "Fluid Meters, Their Theory and Application," Part I, Appendix C, pages 60 to 73.

[9] National Research Council, "Hydrodynamics," Part I, 1932, pages 4 to 24.

[10] E. A. Stalker, "Principles of Flight," Chap. VI, pages 103 to 118. See also reference 5.

*See references 1, 2, 3 and 4.

[11] Bond: "Introduction to Fluid Motion" (E. Arnold & Co., London), pages 19 to 21.

[12] R. J. S. Pigott. "The Flow of Fluids in Closed Conduits," *Mechanical Engineering*, August 1933, pages 497 to 501.

[13] E. Kemler. "A Study of the Data on the Flow of Fluids in Pipes." *A.S.M.E. Transactions*, 1932, HYD 55-2, pages 7 to 32.

[14] Lindquist. "On Velocity Formulas for Open Channels and Pipes." Special Report to the World Power Conference, Sectional Meeting, Stockholm, 1933.

Flow Measurement and Control*

By M. F. BEHAR†

CHAPTER XXIII—POSITIVE METERS

(Continued)

WET TYPES OF POSITIVE GAS METERS

11. Wet Drum

Wet drum meters are used for three kinds of services: As test or precision meters for small low-pressure flows (generally in the laboratory); as station meters for large flows in low-pressure distribution systems (gas companies); and as industrial meters. This last-mentioned service is growing in importance and a complete range of intermediate sizes has become available in recent years, while station meters are giving way to other types. For the well-known wet test meter there is no substitute in the laboratory, but portable precision bellows meters are preferably used in the field.

A wet drum meter consists essentially of a cylindrical casing positioned so that its axis is horizontal, inside which a co-axially mounted cylinder is free to rotate. This inner cylinder—the drum—is divided by partitions into one receiving compartment and four or more measuring chambers. The casing

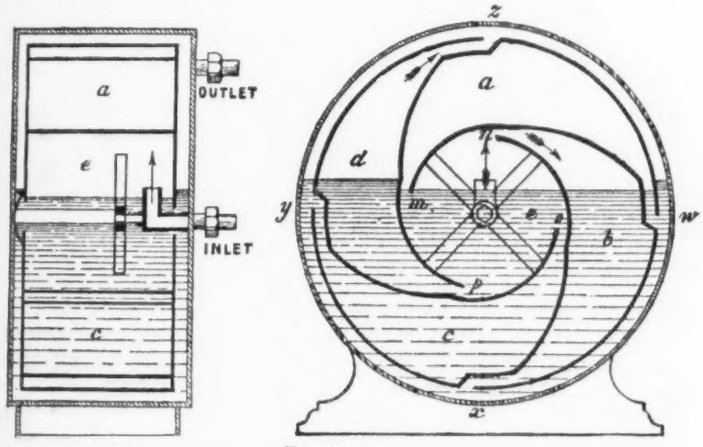


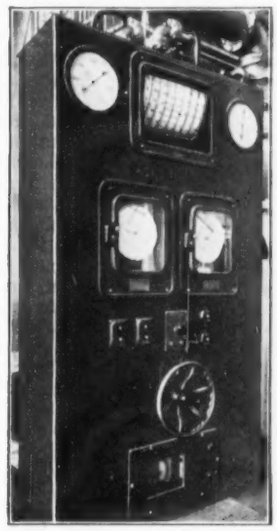
Fig. 23-103

Malam's meter, 1819. Arrows show direction of *gas*—drum turns *counter*-clockwise. Gas enters central chamber *e* and passes through opening *n* to compartment *b*, where its expanding action on water surface and on sides of compartment causes drum to rotate until opening *n* is sealed, trapping a definite volume of gas. A few degrees' further rotation and opening *x* rises above surface of water, making *b* communicate with outlet. Before *n* is sealed, *o* rises and inlet gas can pass into measuring compartment *c*, so inflow is uninterrupted. Before gas has been driven out of *d*, it starts being driven out of *a*, so delivery is likewise continuous. (Illustration from paper on *Station Meters* by Donald McDonald at 1904 A.G.A. Congress; originally from King's *Treatise on Coal Gas.*)

is filled to slightly above its axis with a sealing liquid—generally water—into which a little more than half of the drum is always immersed, so that, as it rotates, each measuring compartment is first nearly emptied of water and then completely filled with water. The effect, of course, is that the above-water volume of each compartment gradually increases and then gradually decreases. The gas inlet, located at the center of one end of the casing, consists of a bent pipe, known as the dry well, ending just above the water level in the receiving compartment. Every measuring compartment is so arranged that during its filling phase it communicates with the inlet and is sealed off from the space between drum and casing; and during its emptying phase it communicates with this space and is sealed off from the inlet. Between these two phases there is a brief intermediate phase, corresponding to 3 to 6° of arc, during which the compartment is sealed off completely. The water in

*Part Six of *The Manual of Instrumentation.*
†Editor, *Instruments.*

FOR BOILER CONTROL



THE BAILEY BOILER PANEL gives complete information for controlling boiler operation. It contains the Bailey Boiler Meter, a Bailey Fluid Meter with which is combined a Boiler Water Level Recorder, and a Bailey Multi-Pointer Gage. The operator has everything right before him to obtain the desired capacity and best efficiency at all times. Request recommendations for your boilers.

PRESSURE GAGE

Extremely accurate gages embodying the dead weight gage tester principle are available in several sizes up to 36" in diameter for indicating at remote points the pressure of steam, water, gas, etc. These gages can be used with any pressures and are particularly suitable for magnified ranges. Ask for Bulletin No. 70.

LONG DISTANCE INDICATOR

Bailey Meter Selsyn Operated Equipment for recording and indicating pressure, temperature, draft, liquid level, etc. at any distance from the source is highly accurate and reliable. Described in Bulletin No. 110.

ADJUSTABLE ORIFICE

The Bailey Adjustable Orifice is for use with Fluid Meter installations where accurate measurements are desired over a flow range of as wide as 160 to 1. Ask for details.

BAILEY METER CO.
1041 IVANHOE ROAD
CLEVELAND, OHIO

Jacob M. Spitzglass

INSTRUMENTATION suffered an irreparable loss on October 1, when Death came to Jacob M. Spitzglass, vice-president and chief engineer of Republic Flow Meters Co. and leading American authority on fluid metering. Born in Russia in 1869, young Jacob defied his parents' wishes at 16 by abandoning religious schooling for practical training. Denied admission to the Kiev Superior School on sectarian grounds, he worked in his father's flour mill and read technical books. In 1904, though supporting a wife and two sons, he sought to enter a technical school in Vienna. Again denied admission, he came to America. In this country, he lost his first job (as a sweeper in a Chicago flour mill) at the end of two weeks because he did not know English well, but his subsequent rise was phenomenal. At 40 he received a B.S. in M.E. from Armour Institute and four years later his M.E.

While making a steam survey for departmental distribution at the Armour Glue Works, he perfected the old Gebhardt Steam Meter, and later joined the Republic Flow Meters Co., makers of this instrument. It was he who developed the electric flow meter which replaced the original steam meter. For his work in developing and perfecting principles of electric flow measurement, he was awarded the Longstreth Medal in 1921 by the Franklin Institute.

Prominent among his activities was work for the A.S.M.E. As secretary of the Research Committee on Fluid Meters he correlated and standardized the available data on fluid flow problems, meanwhile conducting an extensive independent research which culminated in his well known 1922 paper on orifice coefficients. He wrote many other papers on fluid flow and allied subjects. In more recent years he devoted himself to research and the gathering of an extensive library covering all phases of fluid flow. He also developed a domestic house-heating gas burner which is today the most widely sold apparatus of its type in the middle west.

◆ ◆ ◆

O. B. Wilson, formerly manager of the Cleveland, Ohio, Office of The Brown Instrument Co., has been appointed District Manager of the territory comprising Texas, Louisiana and Southern Arkansas with headquarters at Houston, Texas.

◆ ◆ ◆

The **C. F. Burgess Laboratories, Inc.** have been moved September 1st from their former location in New York City to Freeport, Ill., in which locality all sales and manufacturing of the Burgess micro switch, Burgess vacuum contacts, and other products of the organization will be conducted.

any compartment can always flow freely, to all others and to the space between drum and casing. The meter outlet, through the outer casing, is located anywhere above the water line. Thus the gas passes in successively isolated volumes through individual measuring compartments; all of it is measured; there is no leakage or slippage.

The first meter with a drum having a distinct receiving compartment was that of Malam in London (Fig. 23-103) brought out in 1819. This design has only been modified since then in that the receiving compartment is at one end of the drum and the measuring compartments are arranged spirally. Various ingenious designs were patented from time to time. It would take too much space to describe any of these: even drawings and photographs require long explanations. Hinman's drum (American Meter Co.), brought

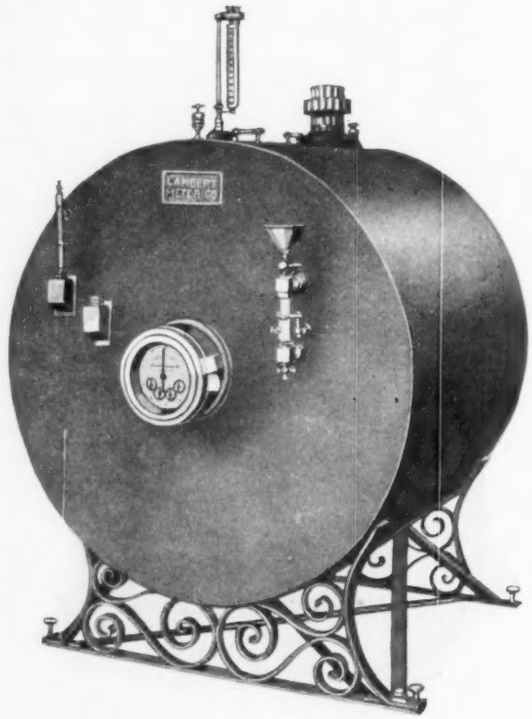


Fig. 23-104

out in 1896 and never yet found to require any significant alteration, may be said to be the most successful in the large sizes which require heavy gauge metal and various reinforcements. It made possible a peripheral speed of 12″ per second, whereas previous types ran 8″ at full rating.

In principle, a wet drum meter should be perfectly positive and it should possess perfect intrinsic accuracy in measuring a gas which suffers no diminution of volume through absorption into the sealing liquid. On paper, various styles of drums can be drawn with equal-volume compartments so shaped that regular flow produces absolutely uniform drum rotation with negligible pressure loss, but the first difficulty arises in connection with keeping the meter size and weight small for a given hourly rate without having the rapid drum rotation disturb levels and cause uneven flow and erratic measurements. In the sheet metal shop, practical difficulties spring up. Many a meter has gone out with unequal compartments, so that although after calibration its total error may be negligible, it is alternately "fast" and "slow" throughout one complete drum revolution.

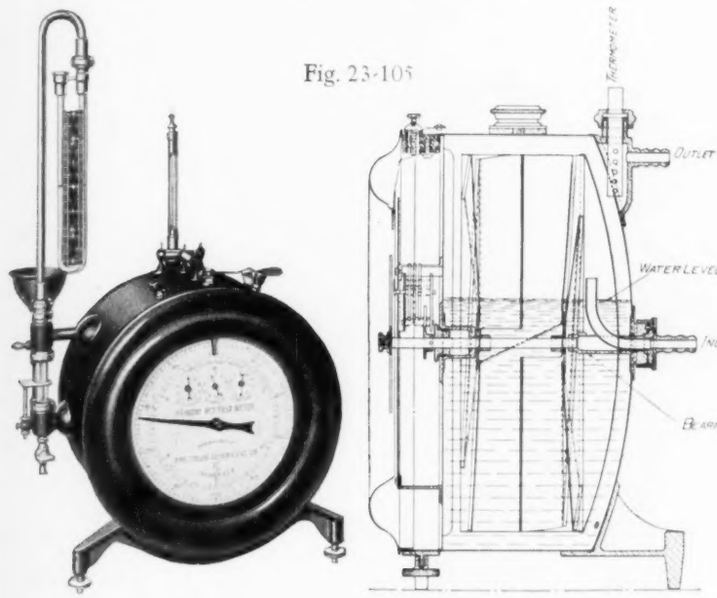
Being generally selected for services where their high attainable accuracy makes their weight and bulk inconsequential, wet drum meters are always provided with devices for exactly leveling the meter and maintaining the liquid level, and with connections for manometers and thermometers whereby registered volumes may be converted to standard cubic feet by reference to tables. Some have been equipped also with demand devices and with recorders. All, of course, are provided with registers—usually of the multiple dial type. The measuring compartments being filled with gas at inlet pressure, it is this pressure that should be used in computations. The pressure drop represents the energy absorbed in driving the meter, and varies with drum speed. For precision work some meters are equipped with inlet and outlet gages and with a differential manometer, also with a plurality of short-range

open-scale thermometers. Careful control of liquid level, however, will always remain the most important factor.

Fig. 23-104 shows one of the Lambert Meter Co.'s Monel metal meters made especially for industrial services in ten capacities ranging from 25 to 1000 cu. ft. per hour. Fig. 23-105 shows the Precision Scientific Co.'s "Sargent" wet test meter, with 1/10 cu. ft. displacement per drum revolution, large dial graduated in 0.001 cu. ft., and three legs of which two are equipped with leveling screws.

Gases to be measured by wet drum meters should be clean (to prevent deposits on surfaces of measuring chambers), dry, free from constituents reacting chemically with the sealing liquid; and at a temperature which should be fairly constant (to prevent appreciable variations in meter tem-

Fig. 23-105



perature) and of course above the freezing-point and well below the boiling point of the sealing liquid. Wet drum meters are used in industry for measuring oxygen, hydrogen and other gases for which bellows meters are unsuitable. The industrial models—especially those made of Monel metal and known as "oxygen and hydrogen meters"—are generally built with such precision and their functional operation is such as to assure a limit of error of 0.2%. With the smaller laboratory meters, the intrinsic accuracy depends upon precision of manufacture, accuracy of manometer and thermometer, and precision and convenience of meter-leveling and water-line devices, so that *in general* their limit of error may be kept within 1% and in some cases (the better meters in the hands of skillful operators) the error may be kept within 0.1%.

Installation requires care in leveling, for if the axis is not horizontal the meter will have to be re-calibrated. Foundation should be solid. Industrial meters should be located in a well-lighted and well-ventilated place where temperature can be maintained above the freezing-point of the sealing liquid. There should be enough space in front of the meter to allow removal of drum for inspection or repair. Connections to permanently-installed meters should be rigid and well fitted so as not to stress the meter head. Before making the inlet connection the dry well should be examined to see that it is properly placed, and the drum should be given a few turns to verify its balance. Frequent attention is required, but maintenance labor, even with the large sizes, amounts only to an occasional half-hour and to a thorough cleaning and inspection at intervals ranging from two to ten years.

12. Nutating Bell

This type is represented by only one make, the Pittsburgh Equitable Meter Co.'s (formerly the Westinghouse). The principle is similar to that of the wobble-plate liquid meter described in §7 but the bell is divided into compartments and its nutation causes rotation of a distributing valve.

Operation of the meter (see Fig. 23-106) is as follows: Gas enters the inlet 1 at *A*, passes through the center cup 4 at *B*, through the inlet port *C* of valve

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FLOW INDICATOR

Dial-type Flow Indicator

Dial and Mercury column types...These Indicators are applicable for indication of flow-rates of water, oils, chemicals, air, gas and steam under wide range of conditions.

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Both types used with MJL Orifice and Flanges...*Write for complete literature.*

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JUST WHAT YOU HAVE WANTED FOR A LONG TIME

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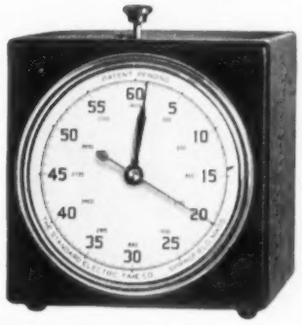
STOP CLOCK



Accurate to better than 1/5 of a second — dead beat—controlled by convenient switch.
Large 3½" dial—3 times larger than an ordinary stop watch—scale divisions of 1/5 second.
A very practical and ruggedly built instrument — avoids the expense and nuisance of jeweller's repairs.
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MANUFACTURERS' LITERATURE

In this department we each month list the printed matter issued by manufacturers. Unless otherwise noted, any of the items listed may be secured free upon application to the issuing firm. Manufacturers who have not yet sent in their printed matter are invited to do so.

A269 **Regulators.** Sept. 1933 edition of 40-page "Copes Catalog" contains discussions of feed-water regulators and allied equipment. 5-color diagrams show operation of various systems. Northern Equipment Co., Erie, Pa.

A270 **Experimenter.** Aug.-Sept. issue contains articles on Chronograph Measurements in Chemistry, Improving Quality of Broadcast Transmission, etc. General Radio Co., Cambridge, Mass.

A271 **Electrolimit Gage.** 12-page booklet shows various forms and discusses applications including continuous-inspection methods. Pratt & Whitney Co., Hartford, Conn.

A272 **Solenoid Valves** of concentric design are listed in 4-page Leaflet 20592. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

A273 **Scientific Instruments** mfd. by C. Reichert, Vienna, Austria. Research, biological, dissecting, petrographical, metallurgical and fluorescence microscopes; micro-photographic, projection, drawing and blood testing apparatus; objectives, eye pieces, dark field and other condensers, saccharimeters, spectroscopes, polarizers, mechanical stages, etc. Literature now available through Pfaltz & Bauer, Inc., New York City.

A274 **Photomicrography.** Reprint of a 22-page article on A Photoelectric Exposure Meter for Photomicrography by Louis Gross and C. A. Johnson, E. E. Free Laboratories, New York City.

A275 **Bearing Thermostats.** Leaflet 1120 on protection of rotating machinery against hot-bearing breakdowns. Elec. Controller & Mfg. Co., Cleveland, O.

A276 **Flow, Level and Pressure Control.** 16-page catalog on "Copes" automatic controllers gives technical details and useful diagrams. Northern Equipment Co., Erie, Pa.

A277 **Contour Measuring Projector.** 38-page booklet describes uses in detail. Bausch & Lomb Optical Co., Rochester, N. Y.

A278 **Grille Type Microphones.** 4-page bulletin on newest forms. Brush Development Co., Cleveland, O.

A279 **Graphic Records.** Their value set forth in folder entitled "Hundreds of Dollars Saved!" Brown Instrument Co., Philadelphia, Pa.

A280 **Microvolter.** Instruction sheets and 8-page technical description of this portable measuring unit. Ferris Instrument Corp., Boonton, N. J.

A281 **Cathode Ray Tube.** Leaflet shows recommended circuits. Allen B. DuMont Labs., Upper Montclair, N. J.

A282 **Colloidal Graphite.** Tech. Bulletin N130 on its use as a high-temperature lubricant. Acheson Oildag Co., Port Huron, Mich.

A283 **Control Power Unit.** Leaflet M9 on Type M94-2 valve-operating "Modutrol" motor for use with potentiometer type instrument. Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

INSTRUMENTS, 330 W. 42nd St. New York City

Please have me supplied with a copy of each piece of Manufacturers' Literature listed below.

.....

.....

Name.....

Position.....

Firm.....

Street and No.....

City.....State.....

13, and through the passages *D* of the valve section 18, into compartments *E* between drum 14 and the fluid *F*. A difference in pressure being created between the compartments *E* in communication with inlet port *C* and upper chamber *G* of the meter, the drum rotates on universal joint 10, causing valve 13 to revolve, keeping its inlet port *C* in communication with the compartments *E* which are increasing in volume, and its outlet port *H* in communication with the compartments *E* which are decreasing in volume.

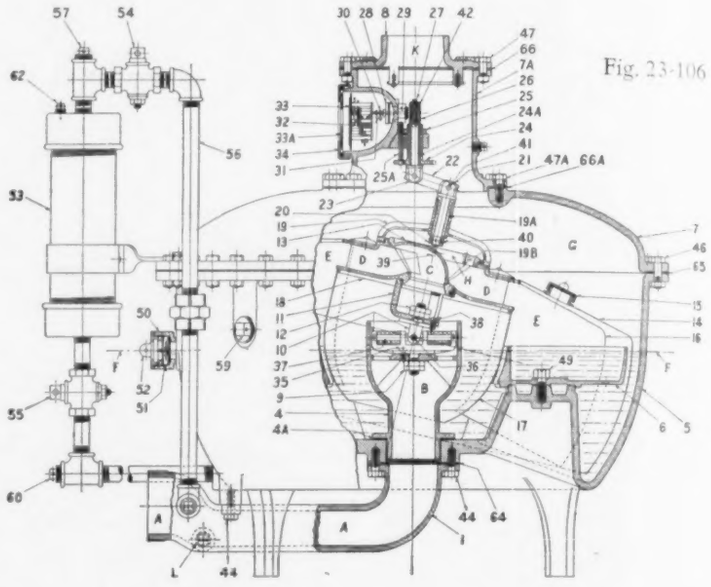


Fig. 23-106

Compartments *E* discharge through passages *D* of the valve section and outlet port *H* of the valve into the upper chamber *G* of the meter. The gas passes on through the movement box 7-A and through the outlet *K* in the movement box cover 8, into the line. The motion of drum 14 is communicated to register 32 by link 22, worm 26 and worm wheel 27, etc.

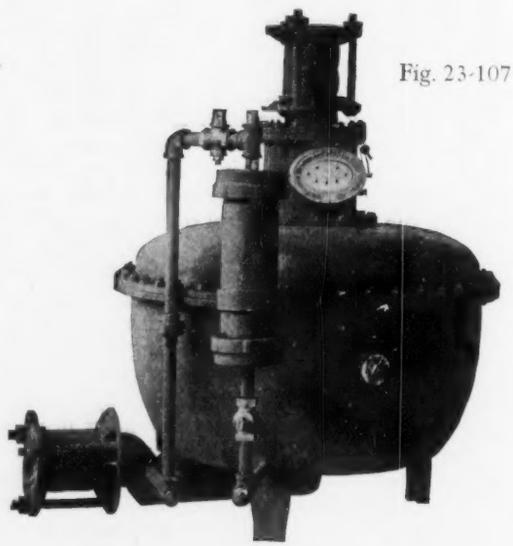


Fig. 23-107

"Adjustment is made by changing the angle of the drum. To adjust the meter, loosen lock nut 25, raise lock pin 25-A and lower adjustment bearing 24, making the meter slower; or raise the adjustment bearing 24, making the meter faster. After adjusting, lock the adjustment bearing with pin 25-A and nut 25. Additional adjustment may be made by shortening or lengthening link 22."

The usual sealing fluid is an oil selected with regard to the metered gas. Accuracy depends on proper maintenance of liquid level, and a limit of error of 0.5% is attainable. In most other respects, too, the characteristics are similar to those of the wet drum type.

NEW INSTRUMENTS

Write Information Section, Instruments Publishing Company, for additional information.

"Speedomax"

Leeds & Northrup Co.

FUNDAMENTALLY, this new instrument is a high-speed null recording potentiometer for measuring small d.c. voltages such as those produced by a thermocouple. The circuit can be readily grasped by comparing it with an L&N "Micromax" potentiometer pyrometer, Fig. 1, in which the detecting element is a galvanometer inserted between the standardized e.m.f. of the pyrometer circuit and the unknown e.m.f. of the thermocouple. This "Micromax" mechanism mechanically adjusts the potentiometer so that the e.m.f. across the calibrated slidewire balances that of the thermocouple, and moves the recording pen correspondingly. In the "Speedomax" circuit, Fig. 2, the potentiometer measuring circuit is retained, but the galvanometer and the mechanical balancing mechanism are replaced by an electrical system by means of which high-speed performance is obtained.

Since the unbalanced e.m.f. in the thermocouple circuit is a matter of microvolts, it is necessary to amplify it to operate the electrical balancing system of the potentiometer. Into the thermocouple circuit is introduced a carbon microphone, driven by an armature energized from the 60 cycle line. This microphone assembly acts as a chopper and modulates the d.c. unbalanced e.m.f. Into the thermocouple circuit is also introduced the primary of a transformer, the secondary of which feeds a voltage amplifier. In operation, if an unbalance in d.c. e.m.f. occurs in the potentiometer circuit, direct current flows and the microphone modulates this so that part of it is converted into a 60-cycle a.c. The d.c. component of the unbalance current flows through the primary of the transformer without effect, but the a.c. component induces an alternating voltage in the transformer secondary which is applied to the voltage amplifier. The direction of flow of the unbalance current through the primary determines the phase of the a.c. feeding the amplifier. The output of this amplifier feeds a transformer having a center-tapped secondary. One end is connected to one thyratron grid and the other end is connected to a second thyratron grid so that the phase of the first thyratron is reversed from that of the second.

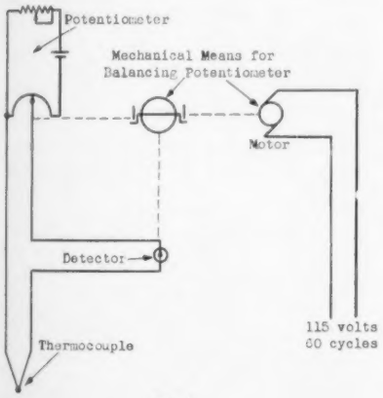


Fig. 1

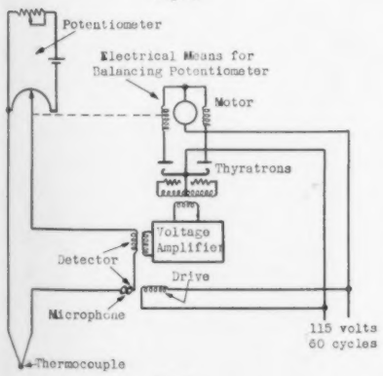


Fig. 2

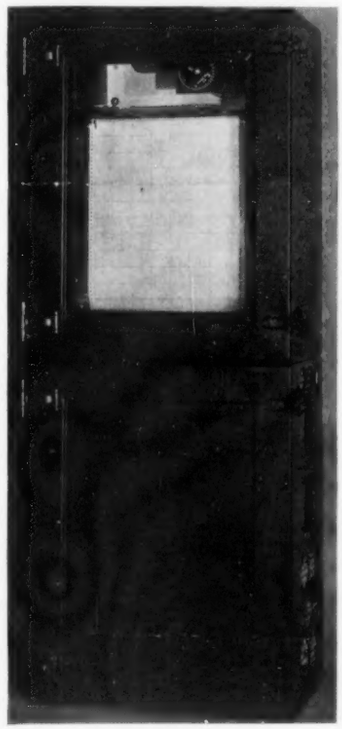


Fig. 3

The plate voltage of the two thyratrons is supplied from the same line as the microphone drive and is therefore of the same phase. In one or the other of the two thyratrons, the grid voltage will be in phase with the plate voltage and this thyratron will pass current. The plates of the thyratrons are connected to the forward and reverse fields of a split-field series reversing motor mechanically connected to the potentiometer slidewire to perform the balancing operation. Therefore, in operation, if there is a sudden increase in temperature the e.m.f. from the thermocouple is momentarily higher than the e.m.f. from the potentiometer and an unbalance current flows in the thermocouple circuit. The a.c. component of the current unbalance is amplified and turns on one of the thyratrons to run the motor in a direction to balance the potentiometer and thus reduce the unbalance current to zero. If the temperature goes low, the unbalance current flows in the opposite direction, thereby reversing the phase of the a.c. component and operating the other thyratron to run the motor to a balance in the opposite direction.

Any tendency to overshoot is eliminated by coupling a tachometer magneto to the shaft of the driving motor and opposing its e.m.f. to the unbalanced e.m.f. in the thermocouple circuit. (This is not shown in Fig. 2) Therefore, if there is a sudden change in temperature, one thyratron tends to move the slidewire and pen rapidly down scale; the magneto driven by this balancing motor produces an opposing d.c. e.m.f. proportional to its speed which tends to bring about a momentary reverse unbalance in the thermocouple circuit, thereby shifting control to the other thyratron and so reducing the balancing speed of the motor. As the motor slows down, the opposing e.m.f. from the tachometric magneto decreases and the control is again shifted to the forward direction, etc., until the potentiometer is finally brought into balance for the new temperature.

The response characteristic of the circuit is such that the recorder pen can cover the 10" chart width in two seconds without overshooting.

Fig. 3 shows the general appearance of a Speedomax recorder adapted for use with a radiation pyrometer to measure and record rapidly varying temperatures in a steel mill.

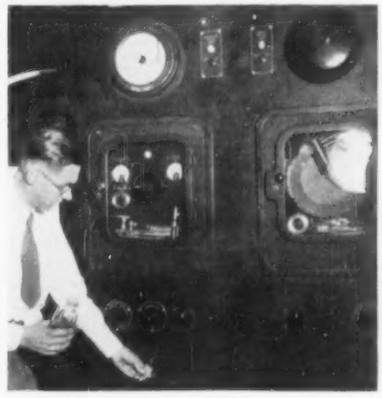
While the foregoing description refers to temperature measurement, the Speedomax is suitable for measurement of other variables, and for their effective automatic control.

◆ ◆ ◆

Mercury Vapor Detector

General Electric Co.

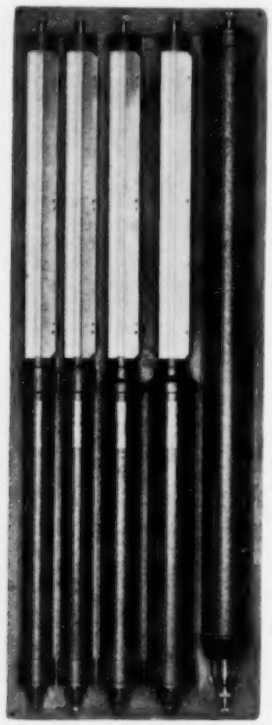
SAID to be three times as sensitive as previous types, this instrument flashes a light and sounds a gong when the continuous sample of mercury-boiler flue gases drawn through its intake duct contains one part of mercury vapor in 10^8 and responds in "a few seconds whereas the previous detector operates only after some minutes." It employs the resonance radiation method: the gases pass between a mercury lamp which emits ultra-violet radiation of the Hg atom wave-length and a quartz-sodium photocell especially sensitive in this region, which therefore responds selectively when mercury atoms in the flue gases absorb the monochromatic radiation. Our illustration shows this new detector at the left; the one at the right employs the older principle based on the darkening of a selenium sulphide film.



Four-stage Fuel Flowmeter

Commercial Engineering Labs.

CHANGEOVER from one stage to the next is entirely automatic in this new instrument designed to measure the rate of flow of such liquids



as gasoline or Diesel oil over an exceptionally wide range. The particular "Research" flow indicator illustrated, Type 18A, measures flows ranging from 2 to 200 gals. per hr. The same degree of precision obtains throughout, because the scales are logarithmic. The cylinder at the right is a centrifugal filter and air trap which automatically removes air and gasoline vapor and prevents vapor lock.

◈ ◈ ◈

Small Stable Phototube

General Electric Co.

OF the vacuum type, this new photoelectric tube, Type FJ-114, is made in an automobile headlamp bulb with standard bayonet base to facilitate mounting in crowded locations. It combines the sensitivity of the usual gas tube and the stability of the usual vacuum phototube. The activation process which produces high sensitivity increases also the infra-red sensitivity to below 12,000 A. U. With an automobile headlamp as the light source (2600° C. or 4700° F.) the new tubes give a 5% or 6% response through a heat-transmitting filter (usual phototubes about 0.5%). An interesting detail is the method of joining the caesiated silver coating of the bulb (the cathode) to the contact in the base. A piece of 0.003" spring material fastened to the contact post presses a piece of 0.0005" platinum foil welded to the tip of the spring, so that it is held against the glass bulb. This platinum foil is fused to the glass, and when the bulb has been coated with its caesiated silver film, the connection is complete.

Pressure Gages

Consolidated Ashcroft Hancock Co.

ACID-PROOF phenol condensate cases of ample mechanical strength make these new gages weigh half as much as cast metal case gages. Sizes

are 4½", 6" and 8½". Bronze or alloy steel Bourdon tubes and Monel bushed movements are employed for ranges up to 600 lbs.; special alloy tube and Nitralloy movements for ranges up to 10,000 lbs.

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Type II Rotoscope

Commercial Engineering Labs.

SAID to have "the greatest speed range of any form of stroboscope" this motor-driven stroboscopic tachometer is of the interrupted line-of-sight type with an Ashdown cylindrical bladed shutter permitting binocular vision. By means of a four-stage gear shift and of a precision governor (set by knob at right) it is possible to observe mechanisms rotating or oscillating at any frequency between 100 and 100,000 per min. The motor runs on 110 volts a.c. or d.c.

◈ ◈ ◈

Magnetic Thickness Gage

Commercial Engineering Labs.

MEASURING the thickness of iron and steel walls by direct contact with one side only is the function of the "Micro-Magnetic" Thickness Gage. The two poles of a powerful electro-magnet are brought in contact with one surface of the wall to be measured, and the wall thickness is read on the scale of a sensitive indicator

which magnifies the actual thickness about ten times. The particular gage illustrated is for gaging the walls of automobile cylinders after rough boring. This gage has two indicators, the left indicating the wall thickness at the top pole of the magnet, and the right indicating the thickness at the bottom pole.

A limit pointer on the dial of each indicator is set by inserting the gage in a master cylinder block at a point in the wall which has the minimum allowable thickness. By using a cable with pulleys and counterweight to suspend the gage above a conveyor, the gage is always within easy reach of the inspector who can follow through the required routine effortlessly. This novel gage has many other applications, one being inspection of steel tanks and cylinders for acceptance tests or for regular inspection tests where one side of the wall is subject to corrosion in service.

◈ ◈ ◈

Improved Microvolter

Ferris Instrument Corp.

INTENDED for factory and field testing and for much laboratory and development work where all the features of a more expensive signal generator are not needed, the new model 10B Microvolter is a self-contained unit for sensitivity measurements covering a frequency range of 150 to 20,000 kc. by means of six coils. Change from one coil to another is made by means of a knob on the front panel. A self-contained 400-cycle oscillator provides 30% modulation at 400 cycles. Power supply is from 115 volt, 60-cycle a.c. line. The Microvolter is portable (see Fig. 1), weighing approx. 20 lbs. Case is of welded sheet aluminum. Triple shielding is employed: case, oscillator shield, and coil system case—all of aluminum. Fig. 2 shows the unit disassembled as far as the coil system, one coil being removed. Each coil is a separably removable assembly and can be replaced by a coil of different frequency

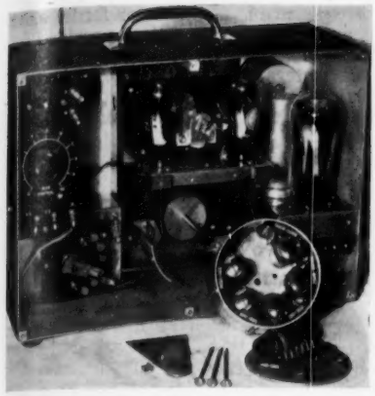


Fig. 2

range, thus providing flexibility. The type of coil system shown in Fig. 2 provides very short and direct RF leads with a minimum of dead leads. Grounding contacts for the two coils adjacent to the one in use prevent undesired resonance effects. The attenuator provides 5-ohm output resistance for voltages up to 1000 microvolts, where the greatest accuracy is required. The vacuum tube voltmeter is fitted with a bias control (left, Fig. 2) accessible when back is removed, adjusted when a tube is replaced.

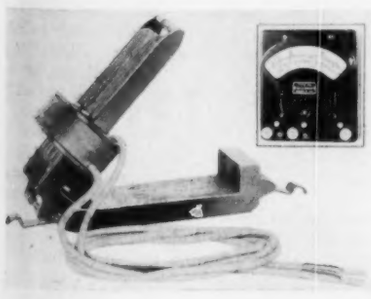
◈ ◈ ◈

Split Core Transformer Test Set

Roller-Smith Co.

WITH this new test set it is possible to obtain a.c. ampere readings as low as ½ amp. and as high as 200 amps. While the ammeter was designed especially for use with the Type CSO transformer, it may be used separately as a self-contained, double range instrument. It has two ranges, 2.8 and 15 amps., when used without the transformer. When used with the transformer two additional ranges are provided, 40 and 200 amps. When using the transformer it is not necessary to open the circuit to be tested as the transformer may be opened to a sufficient extent to slip over a cable or bus bar.

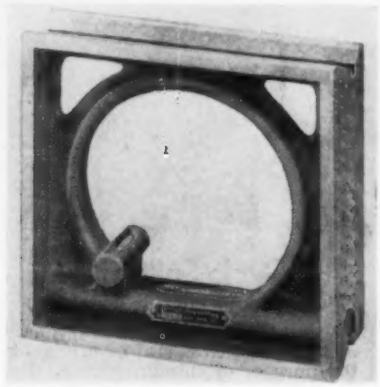
The Type CSO transformer is small, light and rugged. It weighs 4½ lbs. and its overall dimensions are 7" x 3¼" x 3". It is hinged at one end and may be opened about 4¼". The opening is ⅞" x 1⅞" x 2½". The Type PA ammeter is 4½" x 5" x 1⅝", weighs 1¼ lbs. and has a scale 3$\frac{5}{16}$" long. Its accuracy is 2%. It is rugged and will stand any reasonable instantaneous overload. When a larger ammeter is desired, the R-S "Steel-Six" instrument, with a scale length of 5$\frac{3}{16}$", is recommended. The transformer will work equally well with either type of ammeter.



Precision Leveling Square

George Scherr Co.

ON the longitudinal level the scale interval (2 mm.) represents 0.0005" per ft. or 10 seconds of arc. This extraordinary sensitivity is attained by means of an inside-ground vial, filled with distilled chemically pure sulphur ether and rarefied air, and sealed by fusing. A secondary cross level is provided for holding the level horizontal when used on shafts, V-ways, etc. Both levels are permanently imbedded in sulphur. The close-grained cast iron rigid webbed frame has one side plane and the other three of prismatic shape. The side edges are exactly parallel to the axis of the longitudinal level. Guaranteed accuracy is 10 seconds of arc.



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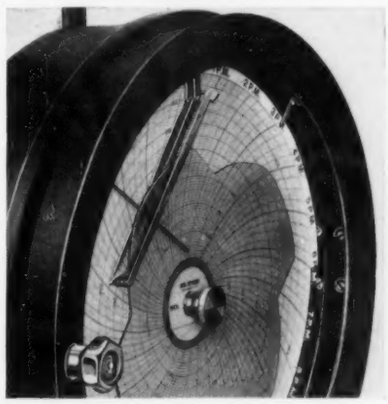
Recording Time Cycle Controller

The Brown Instrument Co.

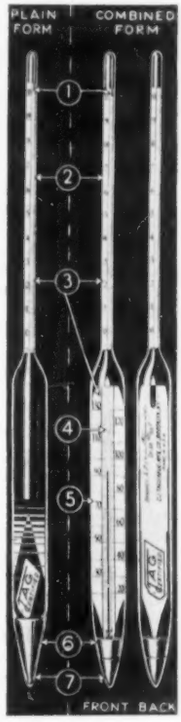
UNOBSTRUCTED by the cam, the pen traces a true record, while the transparent cam not only commands the processing schedule but serves as a standard of comparison whereby the performance of the auxiliaries associated with this new recorder-controller may be checked. Thus there are combined in one case a temperature or pressure time-cycle controller and a virtually independent recorder. The photograph shows how the problem of pen-arm freedom was solved: by letting it travel behind the plane in which the cam and its follower move. Cams are cut by the user from transparent disks by plotting the schedule on a chart and using this chart as a template.



Certified Hydrometers

C. J. Tagliabue Mfg. Co.

SUPPLIED in plain and in combined forms, all with signed certificates guaranteeing accuracy higher than required by the A.S.T.M. or the U.S. Gov't, these new instruments embody a number of improvements, among them some entirely new features. Referring to the illustration—



(1) Red glass strip fused to stem indicates exact position of gravity scale.

(2) Double gravity scale facilitates reading when hydrometer rotates.

(3) Yellow scales with black figures—a combination said to be "ideal" when used in dark oils.

(4) Large-bore lens-front red-backed thermometer tube facilitates reading.

(5) Metal scale is firmly imbedded in solid ballast to prevent slipping. It is 25% longer than ordinary paper scales and its open graduations permit reading to ±¼° F., minimizing commonest source of error.

(6) Solid metal ballast. No mercury to spill if plain form hydrometer is broken. See also *Instruments*, Nov. 1930, page 723.

(7) Streamline tip is easy to clean, lets hydrometer sink quickly in heavy oils and permits use of large-bulb precision thermometer.

◈ ◈ ◈

Graphite Anode Air Cooled Thermionic Tubes

By D. E. Replogle*

WITH a one-piece pure graphite anode in lieu of the metallic plate, results have proved so encouraging that such anodes are now employed in all types of Sylvania transmitting and power amplifier tubes, and may be incorporated in the smaller and more commonplace tubes. For years, tube engineers have been fascinated by the thought of using carbon with its high thermal emissivity, close to that of the Kirchhoff black body. Many attempts have been made to include carbon in the makeup of the anode: the graphite-coated metallic plate has been employed for some time; also, solid carbon plates. These have been assembled from two or more pieces, introducing high contact resistance. When subjected to bombardment just prior to sealing off, the carbon plates, having amorphous carbon on the surface, give off carbon particles, which settle on the inside of the bulb, on the grid, the press, spacers and other members. Carbon coating inside the bulb

*Chief Engineer, Electronics Division, Hygrade Sylvania Corp.

decreases heat dissipation, making the tube operate still hotter and therefore defeating the very purpose of the carbon plate. Carbon deposit on the filament cuts down filament emission, interfering with tube performance. On the press, spacers and other non-conducting members, it causes leakage.

Obviously, commercial carbon must be especially treated prior to mounting and bombardment, so as to reduce the mass to pure graphite. The process begins with a solid carbon block which is precisely machined to final size and shape, then treated for removing impurities. The resultant pure graphite plate is mounted on the stem and placed in the glass bulb. When subjected to bombardment it heats to a bright glow, giving off whatever occluded gases may reside in its pores. There are no impurities to throw off. The volatilization point of pure graphite being much higher than that of the usual molybdenum or nickel, there is no possibility of sputtering conducting particles. When cooled, the graphite mass acts as a getter, having a great affinity for whatever gases may still remain in the evacuated tube.

The graphite anode possesses ample mechanical strength and is rigidly supported by nuts and bolts. With the roughest handling the glass and metal parts will break before the graphite anode. The contact resistance between this one-piece anode and adjacent metal is practically zero. In operation, the graphite anode offers 50% greater heat dissipation than the usual metal plate, without overheating. The glass bulb may be slightly hotter, but its function is to impart that heat to the surrounding air. The graphite anode does not heat to the glowing point even under heavy loads, as contrasted with glowing molybdenum plates even under normal operating conditions, does not undergo any deformation, and there is absolutely no change in tube characteristics, whereas with metallic plates it is necessary to employ a stout truss mounting, and the increased mass of metal complicates the gas clean-up problem.

Exceptional heat dissipation makes graphite anode tubes capable of handling higher outputs for a given rating. Operated at the indicated ratings, the tubes are under little strain and function satisfactorily for long continuous periods. Long total life is experienced because the tube can be processed and aged more critically than is common practice with metallic plate tubes, and because tubes can be made "harder" by reason of the getter action of the graphite. With harder tubes the positive ion bombardment of the filament is reduced to a minimum, which means that the thorium in thoriated filaments is consumed at a far slower rate.

◈ ◈ ◈

Mirror Telephoto System

American Askania Corp.

ONE-FIFTH of the length and much lighter than a conventional lens telephoto system of equal power, this device employs the principle of the reflecting astronomical telescope. Fine adjustments are easily made. Dust and dirt are excluded. A disk carrying six yellow or red filters permits getting sharp details at extremely long distances. Quick-change of focuses is readily accomplished without disturbing other adjustments.

"Cycle Splitter"

Westinghouse Elec. & Mfg. Co.

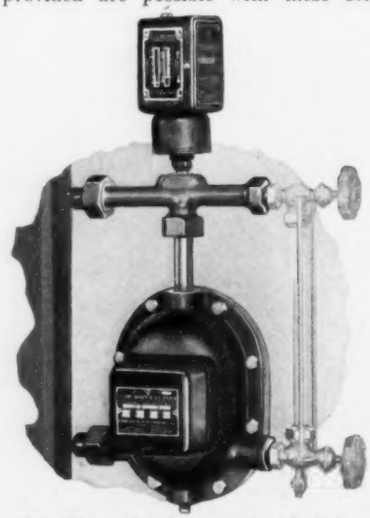
INDICATING brief elapsed time, such as the operation period of a relay, is the purpose of this instrument. The one illustrated employs a synchronous-motor-driven disk with numbers from 1 to 60 punched along its periphery and traveling between a neon lamp and a viewing slot. The circuit of the relay being studied is closed automatically at the instant that zero ("60") passes the slot; when the relay functions the neon lamp flashes (approx. 10^{-3} sec.) and the stenciled number is impressed on the observer's retina.

◈ ◈ ◈

Low Water Cutoff

Minneapolis-Honeywell Regulator Co.

DESIGNED for gage glass mounting, an improved bellows-sealed, packless construction low water cutoff, a duplex switch and water feeder are available for vacuum or pressures up to 25 lbs. The two ways in which protection against low water may be provided are possible with these controls: First, the fire may be shut down and remain so until the boiler is manually refilled. This is accomplished with the low water cutoff connected into the circuit so that if a low water condition occurs a mercury switch cuts off all power. Second, the fire may be shut down and simultaneously an automatic water valve will open to allow refilling of the boiler. The low water cutoff and solenoid valve supply this automatic safety control. If the water feeder valve is not used, the connections provided for it may be used to operate an alarm bell. The water feeder valve is installed directly in the cold water inlet and therefore is free from liming and sediment collection troubles.



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Differential Pressure Control Valve

Northern Equipment Co.

A NEW differential pressure control valve known as the Copes Type SS-2, is an improved design of the Copes Type SS, now permits the valve throttling higher pressure drops than in the earlier design, without chatter or unbalance. Internal parts have also been simplified and made much more rugged. The new valve is made in ¾- to 6-inch sizes, inclusive, in the 250-, 400- and 600-lb. pressure standards. The range of control is 10 to 35 lbs./in.^{2} differential pressure. The valve will handle pressure drops up to 150 lbs., depending on the size. The fittings, either Monel metal or stainless steel as specified, designed for the operating conditions specified by the customer, are said to be accurately balanced under flow conditions and free from chatter within the recommended operating range.

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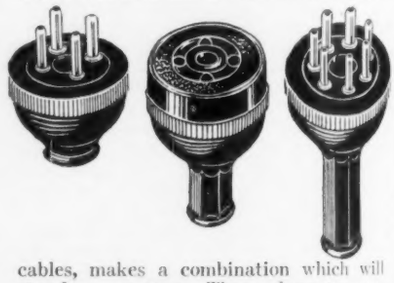
Rubber Capped Plugs

H. H. Eby Mfg. Co., Inc.

FOR apparatus of a more or less portable nature the new Eby line of heavy-duty rubber capped plugs, when used with the newer rubber-covered



cables, makes a combination which will stand severe usage. These plugs are supplied for 4-, 5-, 6- or 7-prong conductor cables in either male or female types with a selection of various styles and sizes of rubber caps as illustrated.

◈ ◈ ◈

Photoelectric Relay

J. Thos. Rhamstine

OUTSTANDING features of the new "Electric Eye" are low cost and simplicity. It employs a dry-disk type Rhamstine photocell, an inexpensive battery and a sensitive relay with accessible adjustment. One large oil company already uses it to test the purity of lubricating oils at filling stations. It will operate on infra-red, which makes possible elaborate burglar alarm systems.

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Pioneer Instrument Co.
Integrating & Recording
American Meter Co.
Morey & Jones, Ltd.
FLUE GAS ANALYZERS
Brown Instrument Co.
FLUXMETERS
Rawson Elec. Inst. Co.
FREQUENCY METERS
Indicating
General Electric Co.
Weston Elec. Inst. Corp.
Recording
Bristol Company
Esterline-Angus Co.
General Electric Co.
Standards
General Radio Co.
FUEL FLOW INDICATORS
Morey & Jones, Ltd.
Pioneer Instrument Co.
FURNACE CONTROLS
Bailey Meter Co.
Bristol Company
Defender Autom'c Reg. Co.
Taylor Instrument Cos.
GAGES
Absolute Pressure
American Meter Co.
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Amplifying
Comparator
Cylinder
Deformation
Baldwin-Southwark Corp.
Dial
Differential Pressure
Bailey Meter Co.
Brown Instrument Co.
Foxboro Co.
Morey & Jones, Ltd.
Pioneer Instrument Co.
Draft
Taylor Instrument Cos.
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Drill
Bausch & Lomb Optical Co.
Filter Rate
Morey & Jones, Ltd.
Flow
American Meter Co.
Bailey Meter Co.
Brown Instrument Co.
Morey & Jones, Ltd.
Liquid Level
American Meter Co.
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Foxboro Co.
Morey & Jones, Ltd.
Pioneer Instrument Co.
Taylor Instrument Cos.
Loss of Head
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Foxboro Co.
Morey & Jones, Ltd.
Pitch Diameter
Pressure
American Meter Co.
Bailey Meter Co.
Baldwin Southwark Corp.
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.
Pressure-Temperature
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.
Pressure & Vacuum
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.
Profile
Rain
Esterline-Angus Co.
Taylor Instrument Cos.
Recording—Distance
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Pioneer Instrument Co.
Taylor Instrument Cos.
Strain
Baldwin-Southwark Corp.
General Electric Co.
Tester
Baldwin-Southwark Corp.
Thickness
Esterline-Angus Co.
Vacuum
Esterline-Angus Co.
General Electric Co.
Taylor Instrument Cos.
Volume
American Meter Co.
Brown Instrument Co.
Foxboro Co.
Water Level for Boilers
American Meter Co.
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Foxboro Co.
Pioneer Instrument Co.
Wind
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
GALVANOMETERS
American Meter Co.
Brown Instrument Co.
General Radio Co.
Rawson Elec. Inst. Co.
Taylor Instrument Cos.
Weston Elec. Inst. Corp.
GAS ANALYTICAL METERS
Electrical
Brown Instrument Co.
GAS FLOW INDICATORS
American Meter Co.
Morey & Jones, Ltd.
GAS LEAK INDICATORS
Taylor Instrument Cos.
GAS-METERS
American Meter Co.
Bailey Meter Co.
Brown Instrument Co.
Foxboro Co.
Dry Test
American Meter Co.
Wet Test
American Meter Co.
GOVERNORS
Pressure
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Taylor Instrument Cos.
Pump
Bailey Meter Co.
Taylor Instrument Cos.
Water Wheel
Baldwin-Southwark Corp.
GRAVITOMETERS
American Meter Co.
GROUND DETECTORS
Weston Elec. Inst. Corp.
HAND TALLEYS
HARDNESS TESTERS
Baldwin-Southwark Corp.
HELIOSTATS
Gaertner Scientific Corp.
HIGH FREQUENCY APPARATUS
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.
HIGH VOLTAGE
Indicators
Weston Elec. Inst. Corp.
Measuring Devices
General Electric Co.
Weston Elec. Inst. Corp.
Testing Devices
General Electric Co.
HUB ODOMETERS
HUMIDITY CONTROLLERS
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
HUMIDITY RECORDERS
Wet & Dry Bulb Thermometers
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
HYDROGEN ION METERS
HYDROMETERS
Taylor Instrument Cos.
HYGROMETERS
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
ILLUMINOMETERS
Weston Elec. Inst. Co.
INDICATORS—See Gages
INDUCTANCES
General Radio Co.
INSTRUMENT CALIBRATION AND REPAIRS
Esterline-Angus Co.
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.
INSTRUMENT TRANSFORMERS
Esterline-Angus Co.
General Electric Co.
Weston Elec. Inst. Corp.
Split Core
Phase Shifting
INSULATION TESTING EQUIPMENT
General Electric Co.
INTERFEROMETERS
Gaertner Scientific Corp.
KEYS AND SWITCHES
General Radio Co.
LABORATORY RHEOSTATS
LACTOMETERS
Taylor Instrument Cos.
LENGTH MEASURING MACHINES
Gaertner Scientific Corp.
LEVELS
Centering
Engineer's, Wye, Precision
Prism
Taylor Instrument Cos.
LOCOMOTIVE INDICATORS
Baldwin-Southwark Corp.
MAGNETIC RELAYS
MAGNETOMETERS
MANOMETERS
Bailey Meter Co.
Bristol Co.
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Morey & Jones, Ltd.
MASTER CLOCKS
Gaertner Scientific Corp.
General Electric Co.
MEGOHMMETERS
MEGOHM VOLTMETERS
Weston Elec. Inst. Corp.
MICROAMMETERS
Esterline-Angus Co.
General Electric Co.
General Radio Co.
Rawson Elec. Instru. Co.
Weston Elec. Inst. Corp.
MICROFARADMETERS
General Radio Co.
Weston Elec. Inst. Corp.
MICROMETERS
Gaertner Scientific Corp.
MICROMETER SLIDES
Gaertner Scientific Corp.
MICROSCOPES
Brinell
Gaertner Scientific Corp.
Measuring
Gaertner Scientific Corp.
Metallographic
Petrographical
Toolmakers'
Gaertner Scientific Corp.
MICROTOMES
MILLIAMMETERS
Bristol Company
Esterline-Angus Co.
General Electric Co.
General Radio Co.
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.
MILLIVOLTMETERS
Bristol Company
Brown Instrument Co.
General Electric Co.
Esterline-Angus Co.
Rawson Elec. Inst. Co.
Taylor Instrument Cos.
Weston Elec. Inst. Corp.
MIRRORS
MODULATION METERS
Esterline-Angus Co.
General Radio Co.
Weston Elec. Inst. Corp.
MOISTURE METERS
General Radio Co.
MOTION RECORDERS
Mechanical
Baldwin-Southwark Corp.
Bristol Company
Esterline-Angus Co.
Foxboro Co.
MOTOR STARTERS
MULTIMETERS
Rawson Elec. Inst. Co.
MULTIPLE PEN RECORDERS
Baldwin-Southwark Corp.
Bristol Co.
Esterline-Angus Co.
Foxboro Co.
MULTIPLIERS
General Electric Co.
Weston Elec. Inst. Corp.
NICKEL SOLUTION TESTERS
NOISE MEASURING SETS
Burgess Labs., Inc., C. F.
General Radio Co.
OHM METERS
Esterline-Angus Co.
General Electric Co.
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.
OIL TESTING APPARATUS
General Electric Co.
Taylor Instrument Cos.
OPERATION RECORDERS
Electrical
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.
OPTICAL PARTS
Lenses, Prisms, Test Planes
Gaertner Scientific Corp.
ORIFICE METERS
Indicating & Recording
American Meter Co.
Bailey Meter Co.
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Morey & Jones, Ltd.
Integrating
American Meter Co.
OSCILLATORS
Weston Elec. Inst. Corp.
OSCILLOGRAPHS
Baldwin-Southwark Corp.
General Electric Co.
General Radio Co.
Automatic
General Electric Co.
Cathode Ray
General Electric Co.
PANTOGRAPHS
Gaertner Scientific Corp.
PERISCOPES
Gaertner Scientific Corp.
PERMEAMETERS
General Electric Co.
PHOTO-ELECTRIC CELLS
General Electric Co.
Weston Elec. Inst. Corp.

PHOTO-ELECTRIC COLOR ANALYZERS
General Electric Co.

PHOTO-ELECTRIC COLOR COMPARATORS
General Electric Co.

PHOTOMETERS
Gaertner Scientific Corp.

PHOTO-MICROGRAPHIC EQUIPMENT
Bawson Elec. Instru. Co.

PHYSICAL TESTING MACHINES
Baldwin-Southwark Corp.

PITOT TUBE METERS
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Morey & Jones, Ltd.
Pioneer Instrument Co.

PLANIMETERS
Automatic Flow Record
Brown Instrument Co.
Foxboro Co.
Linear
Brown Instrument Co.
Baldwin-Southwark Corp.
Radial
Bailey Meter Co.
Bristol Company
Foxboro Co.
Square Root
Foxboro Co.

POLARISCOPES
Gaertner Scientific Corp.

POSITION RECORDERS
Brown Instrument Co.
Bristol Company
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.

POTENTIOMETERS—
Indicating
Brown Instrument Co.
General Electric Co.
Recording & Controlling
Brown Instrument Co.
Standard Cell Comparing
Feussner Type

POWER FACTOR METERS
Esterline-Angus Co.
General Electric Co.
Weston Elec. Inst. Corp.

PRESSURE RECORDERS
American Meter Co.
Bailey Meter Co.
Baldwin-Southwark Corp.
Bristol Company
Brown Instrument Co.
Defender Autom'c Reg. Co.
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.

PRISMS
Gaertner Scientific Corp.

PROCESS TIMING & SIGNALING INSTRUMENTS
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.

PROTRACTOR
Optical

PROVERS
American Meter Co.

PSYCHROMETERS
Recording
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Sling
Taylor Instrument Cos.

PYRHELIOMETERS—
Weather Bureau Type

PYROMETERS
Optical
Radiation
Indicating
Brown Instrument Co.
Taylor Instrument Cos.
Recording
Brown Instrument Co.
Taylor Instrument Cos.
Thermo-electric
Immersion
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Indicating
Bristol Company
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Taylor Instrument Cos.
Recording and Controlling
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Surface Contact
Bristol Company
Brown Instrument Co.
Taylor Instrument Cos.

RADIO FREQUENCY OSCILLATORS
General Radio Company

RADIO SET ANALYZERS
Weston Elec. Inst. Corp.

RADIO TEST PANEL
Weston Elec. Inst. Corp.

RADIO TUBE CHECKERS
General Radio Company
Weston Elec. Inst. Corp.

REFRACTOMETERS

REGULATORS—See Controls

RELAYS
General Electric Co.
General Radio Co.
Weston Elec. Inst. Corp.
Light Sensitive
Burgess Labs., Inc., C. F.
Weston Elec. Inst. Corp.
Vacuum Contact
Burgess Labs., Inc., C. F.
Vacuum Tube
Burgess Labs., Inc., C. F.

REMOTE METERING EQUIPMENT
American Meter Co.
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
General Electric Co.
Morey & Jones, Ltd.
Pioneer Instrument Co.

RESISTANCE—Electrical
General Radio Co.

RESISTANCE COILS

RESISTOR UNITS

RHEOSTATS
General Radio Company

SACCHARIMETERS
Taylor Instrument Cos.

SALINITY INDICATORS
Esterline-Angus Co.

SCALES
Gaertner Scientific Corp.

SEISMOGRAPHS

SELSYN EQUIPMENT
General Electric Co.

SHUNT METERS
Bristol Company
Esterline-Angus Co.

SHUNTS
Esterline-Angus Co.
General Electric Co.
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.

SIGNALING DEVICES—Automatic
Bristol Co.
Brown Instrument Co.
Foxboro Co.
Pioneer Instrument Co.

SPECIAL COILS

SPECIAL ELECTRICAL INSTRUMENTS
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
General Electric Co.
General Radio Co.
Morey & Jones, Ltd.
Pioneer Instrument Co.
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.

SPECIAL INSTRUMENTS
Esterline-Angus Co.

SPECTROGRAPHS
Gaertner Scientific Corp.

SPECTROMETERS
Gaertner Scientific Corp.

SPECTROPHOTOMETERS
Gaertner Scientific Corp.

SPECTROSCOPES
Gaertner Scientific Corp.

SPEED COUNTERS

SPEED INDICATORS
See Tachometers

SPEED RECORDERS
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.

SPEED REGULATORS

STANDARD CELLS
Weston Elec. Inst. Corp.

STOP WATCHES

STRAIN GAGES
Baldwin-Southwark Corp.
General Electric Co.

SUNSHINE RECORDERS
Taylor Instrument Cos.

SURGE INDICATORS & RECORDERS
Esterline-Angus Co.
General Electric Co.

SYNCHRONOSCOPES
Weston Elec. Inst. Corp.

SYNCHRONIZATION FORKS
Electrical
General Radio Co.

SYNCHRONOUS MOTORS
General Electric Co.
Pioneer Instrument Co.

TACHOGRAPH
Baldwin-Southwark Corp.

TACHOMETERS
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Foxboro Co.
Pioneer Instrument Co.
Weston Elec. Inst. Corp.

TACHOSCOPES
Brown Instrument Co.

TELEMETERS
Baldwin-Southwark Corp.
Esterline-Angus Co.
Pioneer Instrument Co.

TELESCOPES
Gaertner Scientific Corp.

TENSOMETER (Huggenberger)
Baldwin-Southwark Corp.

TESTING MACHINES
Fatigue
Baldwin-Southwark Corp.
Impact
Baldwin-Southwark Corp.
Hardness
Baldwin-Southwark Corp.
Portable—Tensile—Compression
Baldwin-Southwark Corp.
Sheet Metal
Baldwin-Southwark Corp.
Oil & Bearing
Baldwin-Southwark Corp.
Universal
Baldwin-Southwark Corp.

THERMIONIC RECTIFIERS
General Electric Co.

THERMO-JUNCTIONS (Electric)
General Radio Co.
Rawson Elec. Inst. Co.

THERMO-VOLTMETERS & AMMETERS
General Radio Company
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.

THERMOPILE—Coblentz Type

THERMOMETERS
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Gas Filled
Defender Autom'c Reg. Co.
Foxboro Co.
Taylor Inst. Companies
Mechanical
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Mercurial
Bristol Company
Taylor Instrument Cos.
Resistance
Brown Instrument Co.
Foxboro Co.
Vapor-Tension
Bristol Company
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Taylor Inst. Companies
Wet & Dry Bulb
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.

THERMOSTATS
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.

TIME INDICATORS
Baldwin-Southwark Corp.

TIME METERS
General Electric Co.

TIME OPERATION RECORDERS
Bristol Company
Esterline-Angus Co.
Foxboro Co.

TIME RECORDERS
Bristol Company
Brown Instrument Co.
Esterline-Angus Co.
Gaertner Scientific Corp.
Foxboro Co.

TIME SWITCHES
General Electric Co.

TIMERS
Rawson Elec. Inst. Co.

TIMING DEVICES
General Electric Co.

TORSIOGRAPH
Baldwin-Southwark Corp.

TOTALIZING INSTRUMENTS
American Meter Co.
General Electric Co.

TOTALIZING RELAYS
Electric
General Electric Co.

TRANSFORMATION POINT RECORDERS
Brown Instrument Co.

TRANSFORMERS (Instrument)
Esterline-Angus Co.
General Electric Co.
General Radio Co.
Weston Elec. Inst., Corp.

TRANSITS
Astronomical
Gaertner Scientific Corp.
Pocket
Taylor Instrument Cos.

TUNING FORKS—
Electrically Driven
General Electric Co.
General Radio Co.
Gaertner Scientific Corp.

TURBIDITY METERS

U-TUBE MANOMETERS
Bailey Meter Co.
Brown Instrument Co.
Defender Autom'c Reg. Co.
Morey & Jones, Ltd.
Taylor Instrument Cos.

VACUUM RECORDERS
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Defender Autom'c Reg. Co.
Esterline-Angus Co.
Foxboro Co.
Taylor Instrument Cos.

VACUUM TUBE BRIDGES
General Radio Company

VACUUM TUBE RELAYS
Burgess Labs., Inc., C. F.

VACUUM TUBE VOLTMETERS
General Electric Co.
General Radio Co.
Rawson Elec. Inst. Co.

VALVES
Automatic Shut-Off
Bristol Company
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Taylor Instrument Cos.
Back Pressure
American Meter Co.
Balanced
Bailey Meter Co.
Baldwin-Southwark Corp.
Brown Instrument Co.
Defender Autom'c Reg. Co.
Foxboro Co.
Taylor Instrument Cos.
Blow-off
American Meter Co.
Diaphragm
Bristol Company
Defender Autom'c Reg. Co.
Foxboro Co.
Taylor Instrument Cos.
Differential
American Meter Co.
Electrically Operated
Baldwin-Southwark Corp.
Bristol Company
Brown Instrument Co.
General Electric Co.
Taylor Instrument Cos.
Motor Operated
Baldwin-Southwark Corp.
Bristol Co.
Pressure Relief
American Meter Co.
Proportional Air-Gas
American Meter Co.
Reducing
Bailey Meter Co.
Taylor Instrument Cos.
Regulating
American Meter Co.
Bailey Meter Co.
Bristol Co.
Brown Instrument Co.
Defender Autom c Reg. Co.
Foxboro Co.
Taylor Instrument Cos.

VENTURI METERS
Bailey Meter Co.
Brown Instrument Co.
Foxboro Co.
Morey & Jones, Ltd.
Pioneer Instrument Co.

VIBROGRAPH
Baldwin-Southwark Corp.

VIBROSCOPE
Baldwin-Southwark Corp.

VISCOSIMETERS
Taylor Inst. Companies

VOLTAGE DIVIDERS
General Radio Co.

VOLT-AMMETERS
Esterline-Angus Co.
General Electric Co.
Weston Elec. Inst. Corp.

VOLTMETERS
Electrostatic
General Electric Co.
Rawson Elec. Inst. Co.
Indicating
General Electric Co.
General Radio Co.
Rawson Elec. Instru. Co.
Weston Elec. Inst. Corp.
Recording
Bristol Company
Esterline-Angus Co.
General Electric Co.
Thermionic Rectifier
General Radio Co.

WATER METERS
Bailey Meter Co.
Brown Instrument Co.
Foxboro Co.
Morey & Jones, Ltd

WATTHOUR METERS
General Electric Co.

WATTMETERS
Indicating
General Electric Co.
Rawson Elec. Inst. Co.
Weston Elec. Inst. Corp.
Recording
Bristol Company
Esterline-Angus Co.
General Electric Co.

WAVEMETERS
General Radio Co.

X-RAY SPECTROMETERS
Gaertner Scientific Corp.

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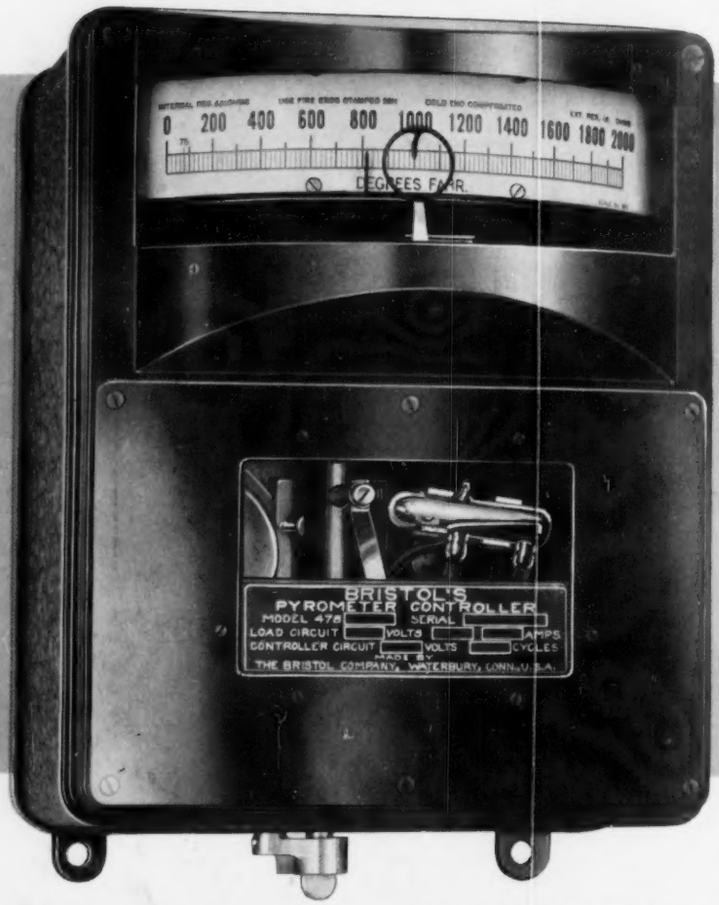

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